

J E T P R O P U L S I O N  
L A B O R A T O R Y

1986

A N N U A L R E P O R T

**T**he Jet Propulsion Laboratory of the California Institute of Technology is a federally funded research center under contract to the National Aeronautics and Space Administration. The people of JPL share a common objective: research and development in the national interest.

JPL has three institutional characteristics that shape its philosophy, mission, and goals: (1) With its ties to Caltech, JPL seeks the highest standards of scientific and engineering achievement with excellence, objectivity, and integrity as guiding principles; (2) as NASA's lead center for exploring the planets, JPL has led the United States in lunar and planetary exploration since the space age began and performs a variety of other research, development, and spaceflight activities for NASA and other agencies; and (3) as a federally funded research and development center, JPL helps the nation solve technological problems.

JPL's primary mission evolved from pioneering rocket research through guided-missile work to spaceflight projects. Today JPL is a preeminent national laboratory with a budget of more than \$800 million and a workforce of more than 5,000.

The Laboratory built and launched the first U.S. satellite, Explorer 1. JPL's flight projects have included the Rangers and Surveyors—pathfinders for the Apollo manned Moon landings; the Mariners to Mercury, Venus, and Mars; the Vikings to the surface of Mars; and the Voyagers to Jupiter, Saturn, and Uranus.

When U.S. policy dictated energy self-sufficiency, JPL responded with research and development in solar photovoltaics, solar thermal energy, and electric vehicles. Today's emphasis on new defense efforts is being answered by JPL in a number of fields described in this report.

The year reported on here, 1986, was a period of hard work and progress to help NASA recover from the accident of the space shuttle Challenger. It was also a year of great strides in many fields of technology, including new computer architecture, robotics, machine intelligence, and astrophysics.

Still, the Laboratory's major role continues to be the exploration of the solar system, including Earth. JPL is conducting programs in Earth sciences and is exploiting technology to expand the observations of our oceans and climate from space.

## **C O N T E N T S**

|                                   |           |
|-----------------------------------|-----------|
| <b>DIRECTOR'S MESSAGE</b>         | <b>2</b>  |
| <b>FLIGHT PROJECTS</b>            | <b>4</b>  |
| <b>SPACE SCIENCE</b>              | <b>14</b> |
| <b>GEODYNAMICS</b>                | <b>20</b> |
| <b>ADVANCED TECHNOLOGY</b>        | <b>24</b> |
| <b>DEFENSE AND CIVIL PROGRAMS</b> | <b>32</b> |
| <b>TELECOMMUNICATIONS SYSTEMS</b> | <b>38</b> |
| <b>INSTITUTIONAL ACTIVITIES</b>   | <b>44</b> |

A description of work accomplished under a contract between the California Institute of Technology and the National Aeronautics and Space Administration for the period January 1 through December 31, 1986.

**JET PROPULSION LABORATORY**  
California Institute of Technology  
Pasadena, California



Dennis Luman

The year opened with extraordinary promise and expectation. It was to be the "Year of Space Science," inaugurated by Voyager 2's flyby of Uranus on January 24. Later we would celebrate the launches of Galileo, Ulysses, and Hubble Space Telescope. Comet Halley would make its once-in-a-lifetime appearance, and the year would close with Galileo's approach to the asteroid Amphitrite.

The Voyager Uranus encounter was a spectacular success. After landmark observations of Jupiter in 1979 and Saturn in 1981, Voyager 2 gave us our first close view of the distant giant Uranus, its complex rings, inclined magnetic field, and diverse moons. Images of the innermost satellite, Miranda, show fantastic geological formations that make it one of the most bizarre objects in the solar system. Voyager's achievements are a credit to the people who managed the spacecraft systems, reconfigured its onboard computer, and introduced image compression and target-motion compensation—all from 3-billion kilometers away and after eight years of flight.

On January 28, only four days after Voyager's encounter with Uranus, came the tragic Challenger accident. All shuttle flights were postponed and the Centaur upper stage was canceled. The Galileo mission, which depended on Centaur, was hard hit, and all space-science missions faced delays of two years and more. Those events necessitated a thorough re-evaluation of NASA's options for a strong, continuing planetary science program. Throughout the year, JPL worked closely with NASA to plan for the resumption of planetary flights.

We spent considerable effort to develop means of responding to, and compensating for, slips in shuttle launch dates through laborious replanning of missions. The Magellan mission to Venus will be the first JPL project to fly when shuttle operations resume. Galileo, scheduled for a 1989 shuttle launch, will follow a new trajectory that will send it whipping around the Sun and Venus and twice by the Earth en route to Jupiter. The new route compensates for the reduced performance of the launch system but adds three and one-half years to the trip time.

The year put immense demands on our skills. One source of our strength is the caliber of our people. Another is our close relationship with the Caltech campus. A third is our hands-on involvement with major flight programs. We stress the need for at least one in-house program to maintain our technical expertise and familiarity with flight systems. JPL today continues a widely recognized tradition of excellence that reaches back 42 years.

Yet a fourth source of strength is the breadth and diversity of our research and advanced-technology efforts. In recent years, Defense and Civil Programs have continued at about 25 percent of our total efforts, providing support to the development of new techniques, materials, and devices for future missions. Three projects delivered prototypes of complex information-processing systems, and all went through successful acceptance-testing and represent fundamental new capabilities.



The Advanced Microelectronics Program continues, with strong Caltech faculty collaboration, the development of advanced concepts and devices to support NASA and other sponsors, establishing JPL as a center of excellence in the field. The Hypercube computer project continued as a leading concurrent-computation research effort.

Those and other new programs make increasing demands on our facilities. The Central Engineering Building was occupied in 1986. Construction continued on the Earth and Space Science Laboratory. Groundbreaking for the new Microdevices Laboratory was scheduled for early 1987. The Engineering Support Building was approved for construction starting in 1987.

Now let us look back on some major achievements during the year. In addition to the Uranus encounter, the International Halley Watch produced a torrent of valuable scientific data. JPL coordinated the work of more than 1,000 astronomers from 51 countries. The Deep Space Network played a critical role in the acquisition of Halley data from space. NASA selected the scientific investigators for the planned comet rendezvous mission. Mars Observer progressed with contract awards for the spacecraft and the selection of its scientific instruments. NASA is considering a long-term emphasis on Mars exploration, and the Observers may be the first in that exciting new program. The TOPEX/Poseidon ocean-altimetry mission was approved for a new start, and plans are proceeding for a joint U.S.-France program and a 1991 launch aboard Ariane. TOPEX continues JPL's emphasis on satellite studies of the planet Earth that have included shuttle-borne observations and SEASAT.

This has been a tough year for the NASA community and a challenge to all of us at JPL. The people of JPL met the challenge with great competence, innovation, and skill. At year's end, events show that JPL remains a strong and resilient institution.

A handwritten signature in black ink, appearing to read 'Lew Allen', with a stylized, flowing script.

Lew Allen  
*Director*

**V**oyager continues to be the star of the Laboratory's ongoing flight projects. Completing its last planetary encounter in 1980, Voyager 1 cruises on through interplanetary space, searching for the edge of the solar wind. Voyager 2 sails toward its next encounter—Neptune, the eighth planet from the Sun—on August 24, 1989. Then Voyager 2 will join Voyager 1 in the search for the edge of the Sun's sphere of influence.

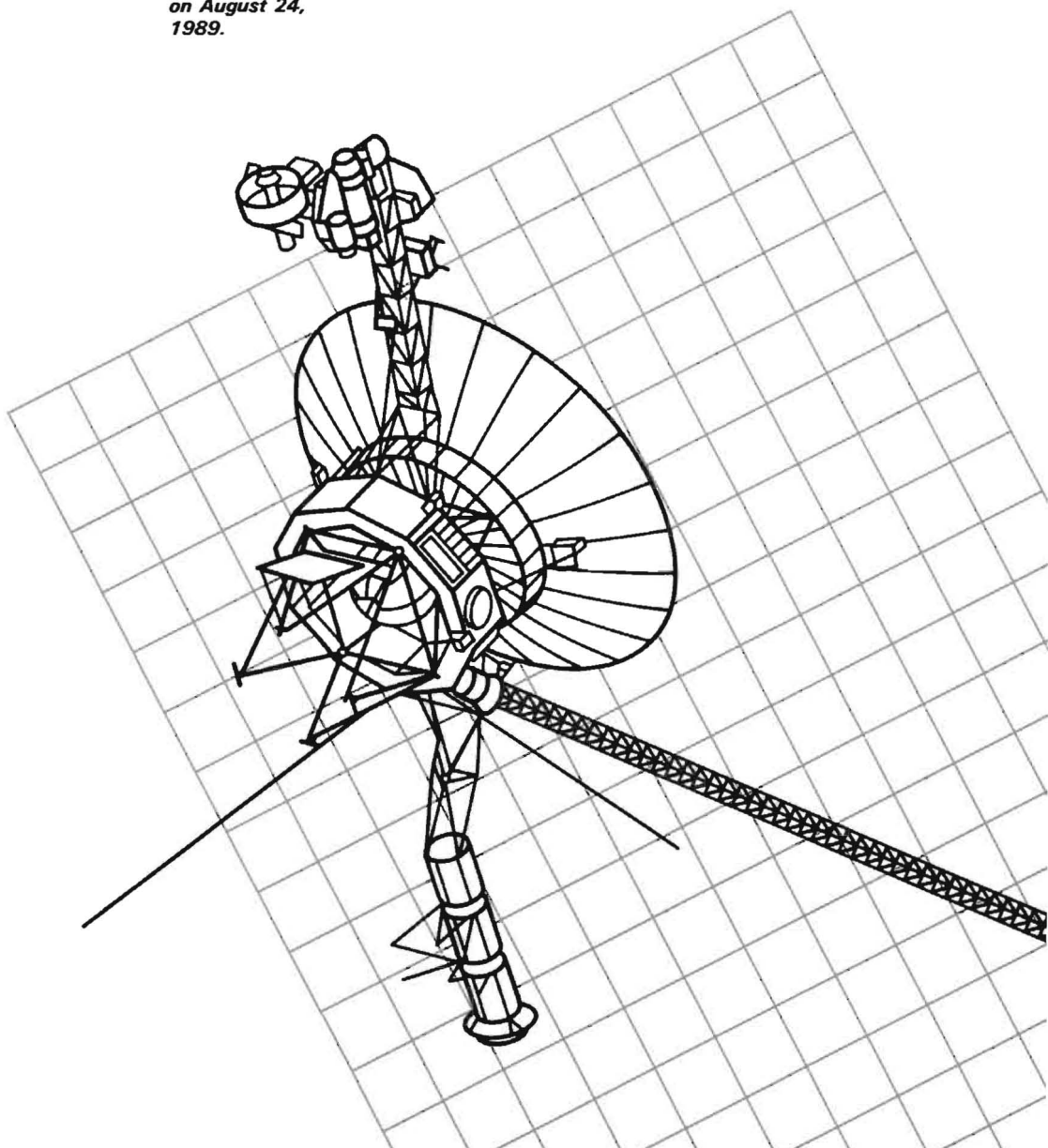
While the Challenger accident delayed the launch of JPL's other flight projects, work continues on Galileo, Ulysses, Magellan, and Mars Observer. Planning, too, continues for other missions still far in the future.

## VOYAGER

On January 24, Voyager 2 became the first spacecraft to explore a planet unknown to ancient observers when it passed 82,000 kilometers from the cloud tops of Uranus.

Since Earth-based observations of Uranus provided only the sketchiest of information, much of the mission's planning required procedures never tried with Voyager. It is a tribute to the men and women of the Voyager project, the Deep Space Network, and other support groups that the operations and data collection were nearly flawless. Voyager discovered ten satellites, myriad ring structures, and a bizarre magnetic field around the 3-billion-kilometer-distant planet.

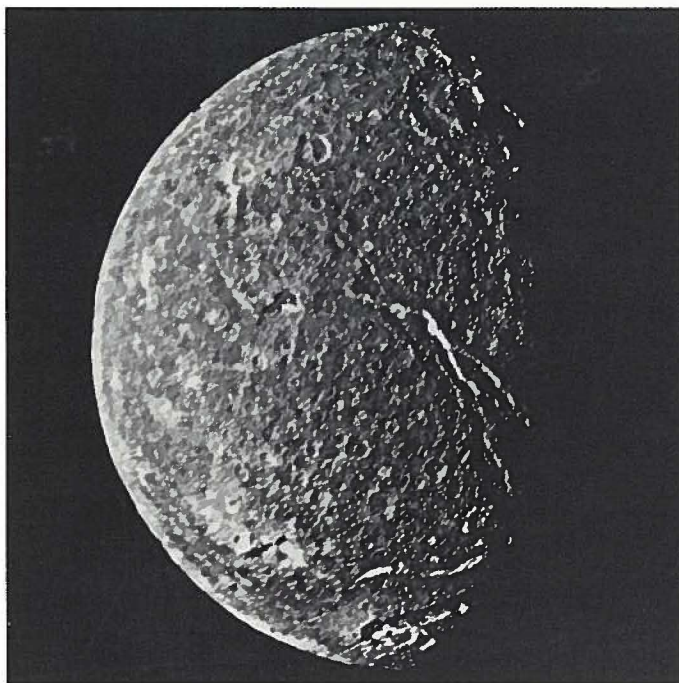
*The identical Voyager spacecraft have been operating for more than nine years. Voyager 1 is searching for the interstellar wind, and Voyager 2 continues on its route to Neptune after its encounter with Uranus, January 24. Voyager 2 has a date with Neptune on August 24, 1989.*



*Miranda, the innermost of Uranus' five major satellites, exhibits topography that one Voyager scientist called "the most bizarre we've seen yet in the solar system." Some terrain appears extremely old, while other regions appear young. Voyager's engineers and scientists used new and daring techniques to take this and other pictures of the strange body.*

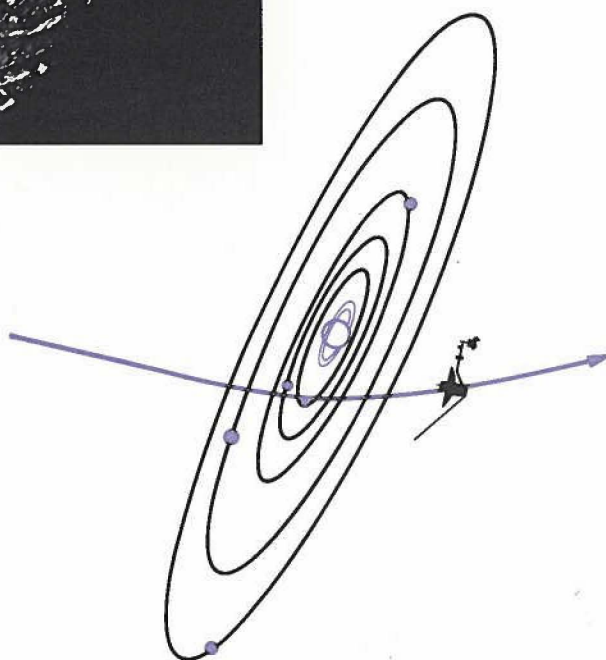
*Three of the ten tiny Uranian satellites that Voyager scientists discovered appear in this one photograph. The temporary designations beside the satellites indicate the year of discovery, the planet, and the order of discovery.*

Before Voyager 2's encounter, estimates of Uranus' rotation period ranged from 10 to 24 hours. The discovery of narrow rings in 1977 and studies of their motions led to an estimate of about 15.6 hours for the Uranus day. However, Voyager's planetary radio astronomy and magnetometer experiments fixed the rotation of the planet's magnetic field (and presumably the bulk of its interior) at  $17.24 \pm 0.01$  hours. The interior was already thought to be predominantly water, methane, and ammonia, but the longer rotation period implies that those melted ices are present throughout almost



*The surface of Titania, the largest of Uranus' five major satellites, is scarred by long, deep fault valleys. The valleys indicate some degree of geologic activity in the satellite's history.*

*Uranus rolls along on its side as it orbits the Sun, pointing its south pole sunward during Voyager 2's encounter. The spacecraft's track through the tilted Uranian system (right) shows why most of the data-gathering of the encounter occurred within a short portion of a single day. Satellites are (in increasing distance from Uranus) Miranda, Ariel, Umbriel, Titania, and Oberon.*



all of the interior rather than in a deep, well-separated ocean core.

Voyager's radio science disclosed a distinct layer of methane clouds below the depths seen in images. A few low-contrast cloud features were tracked in Voyager images long enough to show that south of 25 degrees south latitude the wind blows easterly, opposite the direction predicted for a planet that gets most of its sunlight at the south pole. Wind speeds reach a maximum of about 200 meters per second near 60 degrees south latitude.

Voyager yielded two atmospheric radio-occultation profiles, each within a few degrees of the equator. Combined with infrared interferometer-spectrometer results, they show a minimum temperature of 52 kelvins near the 0.1-bar level and higher temperatures above and below. Radio occultations also revealed a layered ionosphere with an extended topside that may reach 10,000 kilometers or more above 0.1 bar. Possibly related to the ionosphere, an extended hydrogen atmosphere exists that may envelop the rings.

The infrared and radio-science instruments helped scientists to deduce that hydrogen and helium, respectively, make up 85 and 15 percent ( $\pm 5$  percent) of the atmosphere. Equatorial temperatures and those at both poles are nearly identical, but dips of 1 or 2 kelvins are noted at midlatitudes, implying that latitudinal redistribution of heat occurs. Internal heat sources make up a smaller percentage of Uranus' total heat output than at Jupiter, Saturn, or Neptune, so the internal sources may be negligible.

Uranus's rings are dark. They reflect about 5 percent of the sunlight that strikes them and are probably composed of carbonaceous material. Instead of being organized into broad sheets of particles, the Uranian rings are generally grouped into ringlets only a few kilometers wide. Exceptions are



the 2,500-kilometer-wide ring designated 1986U2R and the more nearly continuous dust-sized particles seen by Voyager 2 in a 96-second exposure while Voyager was in Uranus' shadow.

Radio-science and photopolarimeter measurements seem to indicate that at least the epsilon ring, and perhaps each of the rings, is almost devoid of particles between a micrometer and a few tens of centimeters in size. The radio-science occultation also showed no rings other than those in Voyager images; however, photopolarimeter data obtained during stellar occultations may provide evidence for a substantial number of extremely narrow ringlets or ring arcs.

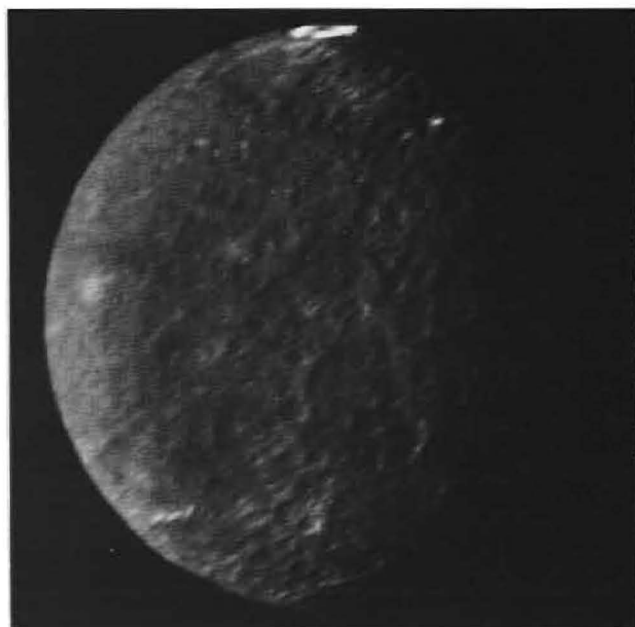
Before Voyager 2's Uranus encounter, five satellites were known: Miranda, Umbriel, Oberon, Titania, and Ariel. None had been more than a point of light, even in the best telescopes. Their sizes had been estimated from relative visual and infrared brightnesses until Voyager 2 measured their sizes and photographed their surfaces.

Most intriguing of the major Uranian satellites is Miranda, discovered by Gerard Kuiper in 1948 and named for a character in Shakespeare's *The Tempest*. Less than 500 kilometers in diameter, the satellite has an amazingly diverse surface, particularly in light of its small size and low temperature ( $86 \pm 1$  kelvins). Voyager 2 passed within 30,000 kilometers of Miranda, so it was possible to photograph much of its surface at resolutions of 1 kilometer or less.

Ten new satellites were discovered in Voyager 2 images. The largest, with a diameter of  $170 \pm 10$  kilometers, was found December 30, 1985. Nine more were discovered between January 3 and 21, 1986. Although none of the last nine was seen closely enough to resolve a disk, size

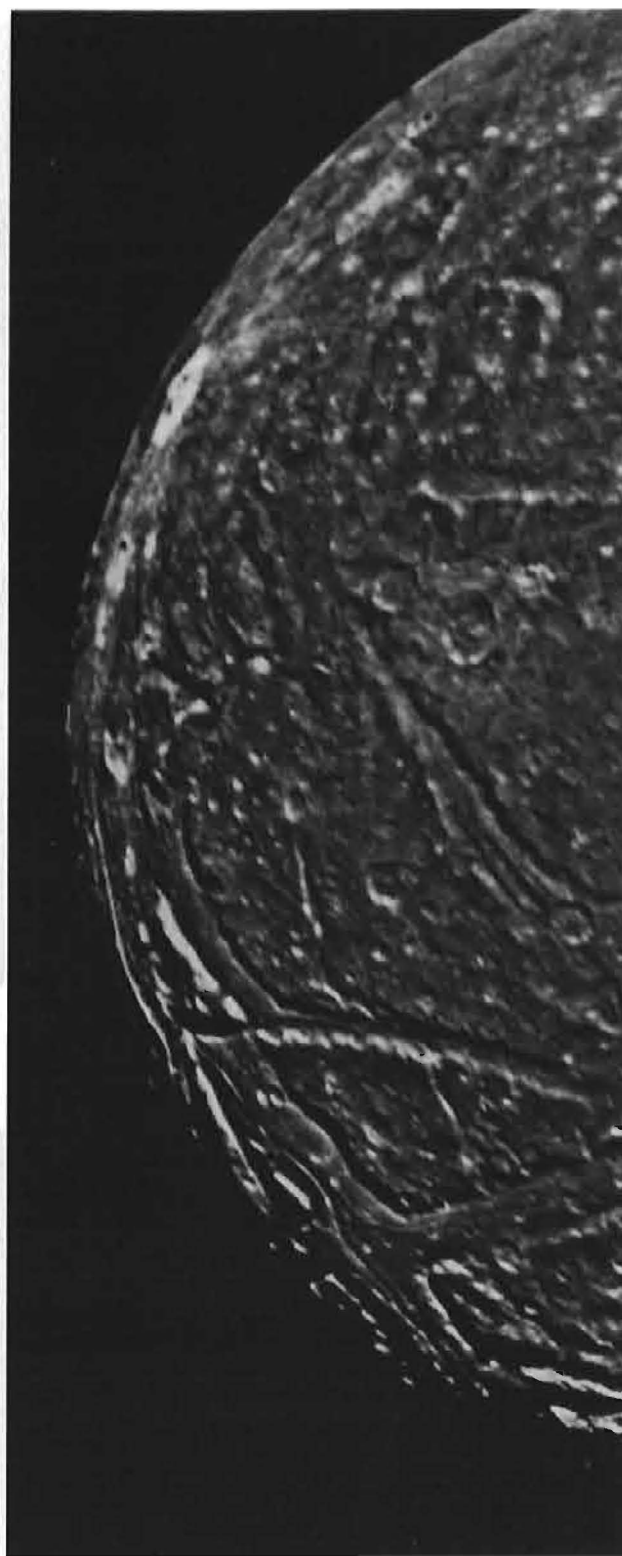


*When Voyager 2 looked back over its shoulder at the backlit rings of Uranus (above), it found that the space between them was almost filled with tiny dust particles that are about one micrometer in diameter. Craters in Umbriel's southern hemisphere (right) show that the satellite was heavily bombarded.*





*Ariel, at right, has undergone extreme geologic change. Most of the evidence of early cratering has been erased by more recent surface melting and other geologic activity. Ariel, like the other large Uranian satellites, appears to be a combination of rock and ice.*

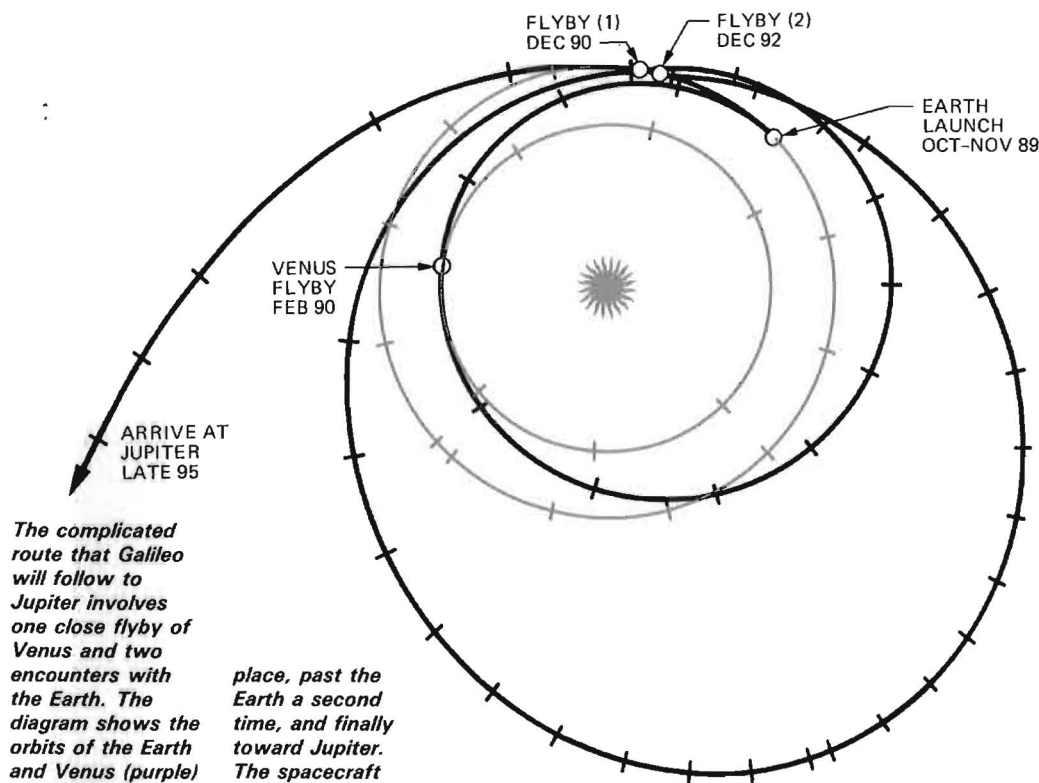


can be estimated by knowing that none is large enough to be resolved (an upper limit of size) and by assuming that none reflects more than 10 percent of the sunlight it intercepts (a lower limit). All are inside Miranda's orbit, and all but 1986U7 are outside the rings. Satellites 1986U7 and 1986U8 are thought to shepherd the epsilon-ring particles through gravitational interaction.

The first direct indication of a Uranian magnetic field was from radio emissions detected by Voyager 2 on January 19, five days before the spacecraft's closest approach. Voyager 2 entered the magnetic field about eight hours before closest approach and remained inside the field for about 45 hours. The planet's magnetic field is well represented by that of a dipole tilted 60 degrees from the rotation axis and offset toward the dark (north) pole by three-tenths of Uranus' radius. Uranus is, therefore, the first planet found to be an oblique rotator.

As with other planets, the dipole field is deformed by the solar wind, resulting in a long magnetic tail. Electrons and protons dominate the charged-particle population in the magnetosphere. The proton fluxes are too small to cause significant distortion of the magnetic field but are large enough to darken methane on satellite and ring-particle surfaces in geologically short times. It is possible that the proton bombardment causes the rings and the small satellites to have low reflectivities.

Now the Voyager project phases into the Neptune/Interstellar Mission that includes investigating the interplanetary and interstellar media by both spacecraft and includes Voyager 2's Neptune encounter at 0400 GMT, August 25, 1989. By then, the Voyagers will have been in flight for a dozen years, more than three times their planned lifetime.



*The complicated route that Galileo will follow to Jupiter involves one close flyby of Venus and two encounters with the Earth. The diagram shows the orbits of the Earth and Venus (purple) and Galileo's flight path (black). After launch, Galileo will fly to Venus, back to the Earth, to the asteroid belt where a propulsive maneuver will take*

*place, past the Earth a second time, and finally toward Jupiter. The spacecraft (below) will undergo several changes from earlier designs to protect it from the Sun during its trip through the inner solar system.*



And plans are being made to keep both alive until 2010, more than 33 years after launch.

## GALILEO

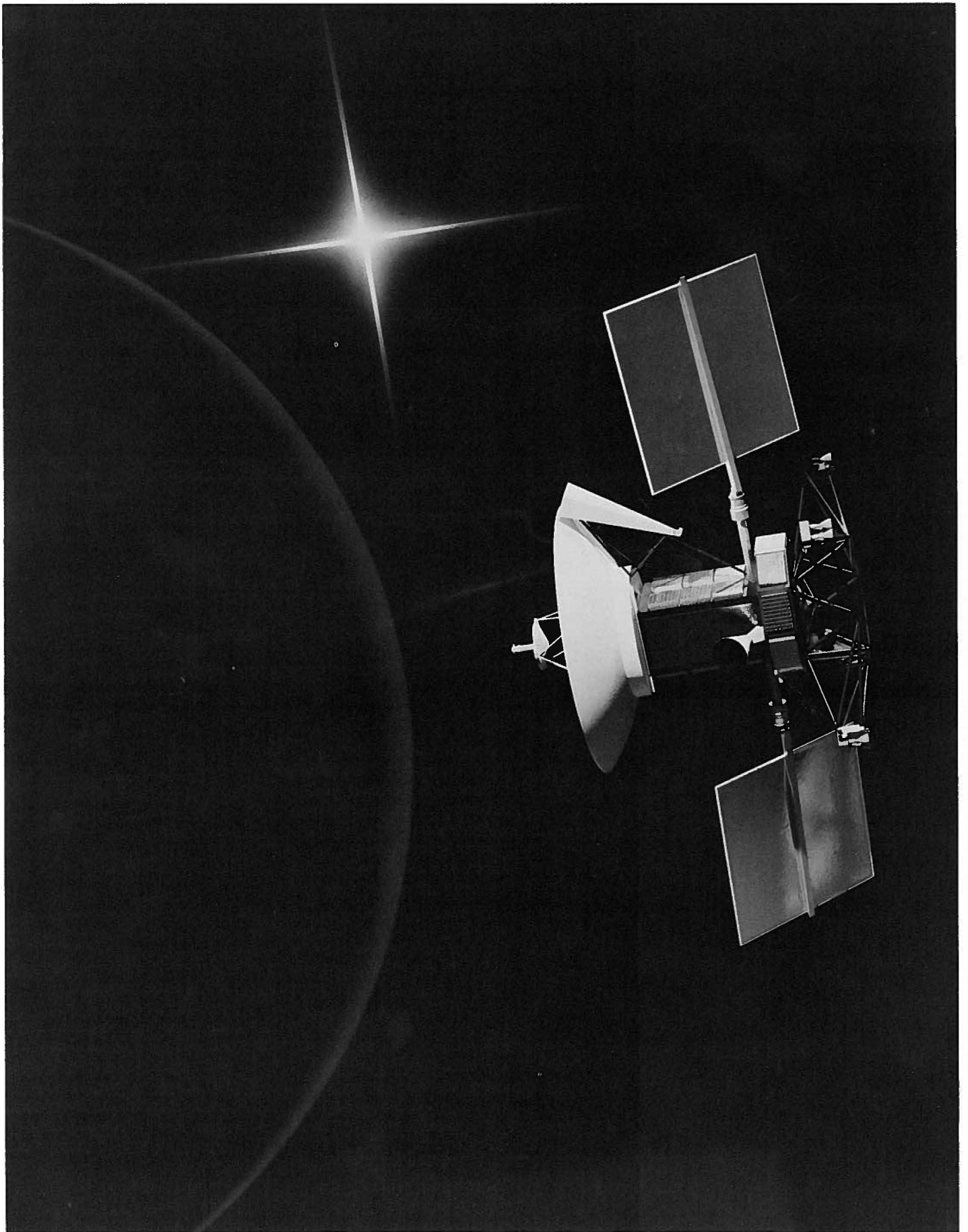
The Galileo project will provide the first direct sampling of Jupiter's atmosphere and the first extended observations of the largest planet, its Galilean satellites, and its intense magnetic environment.

By January 1, 1986, Galileo had arrived at Kennedy Space Center after launch-vehicle testing had been completed at JPL in 1985. Integration activity was under way when the Challenger accident occurred, which later canceled the May launch.

Nevertheless, activities at the Cape continued with the replacement of spare parts that were transferred to Magellan. Ground data-system testing was completed, as was a launch and trajectory-correction-maneuver exercise. Design work for the early months of the cruise to Jupiter, the preparation of flight-team procedures, and contingency planning continued. The flight spacecraft was mated to the Centaur upper stage.

When the Centaur/shuttle program was canceled, an intensive effort was begun to find a new launch vehicle and to redesign the mission to fit new shuttle standards. Galileo will be carried to Earth orbit atop a two-stage Inertial Upper Stage in the space shuttle cargo bay. Launch is planned for November 1989.

Along with a new launch booster, Galileo has a redesigned trajectory involving a gravity-assist flight past Venus three months after launch and two gravity-assist flights past Earth (13 and 37 months after launch) before taking the final flight path to Jupiter. The new trajectory is dubbed VEEGA, for Venus-Earth-Earth Gravity



Assist. With a November 1989 launch, Galileo will arrive at Jupiter in November 1995.

The new trajectory provides a full ten orbits of Jupiter. The satellite encounters will provide images 20 to 100 times better than any obtained before. VEEGA requires changes to Galileo for thermal protection, telecommunications, and the six-year cruise. The trip to Venus will carry Galileo closer to the Sun than previously planned flight paths, posing severe thermal problems, to be solved with thermal shades and shields and with different external blanket material.

The probe is now at JPL. Its science instruments are being upgraded, and reintegration is scheduled for early 1988.

## MAGELLAN

Magellan will map Venus with an imaging radar. It will return data about the geological processes that formed Venus' surface and that may still be active in the interior.

The delay of the shuttle program caused the rescheduling of Magellan's launch, now slated for April 1989. Thus, Magellan will be JPL's next planetary launch. Instead of the usual five-month cruise to Venus, Magellan's will take 15 months, looping one and a half times around the Sun en route.

Much effort was spent replanning the mission after the schedule slip and the cancellation of the Centaur program. Work on the imaging radar and the spacecraft is progressing toward the start

of assembly, test, and launch operations in 1987.

The imaging radar, the instrument for Magellan's primary scientific investigation, will show features on Venus' surface as small as 150 meters. Topography measurements made by a radar altimeter will aid in the interpretation of the radar images.

Venus is Earth's nearest planetary neighbor and is similar in size, mass, and mean density to Earth. Thus, Venus may hold clues to the early processes that formed Earth and its atmosphere. Venus may also help scientists to understand the different geological processes that may have formed each of the inner planets.

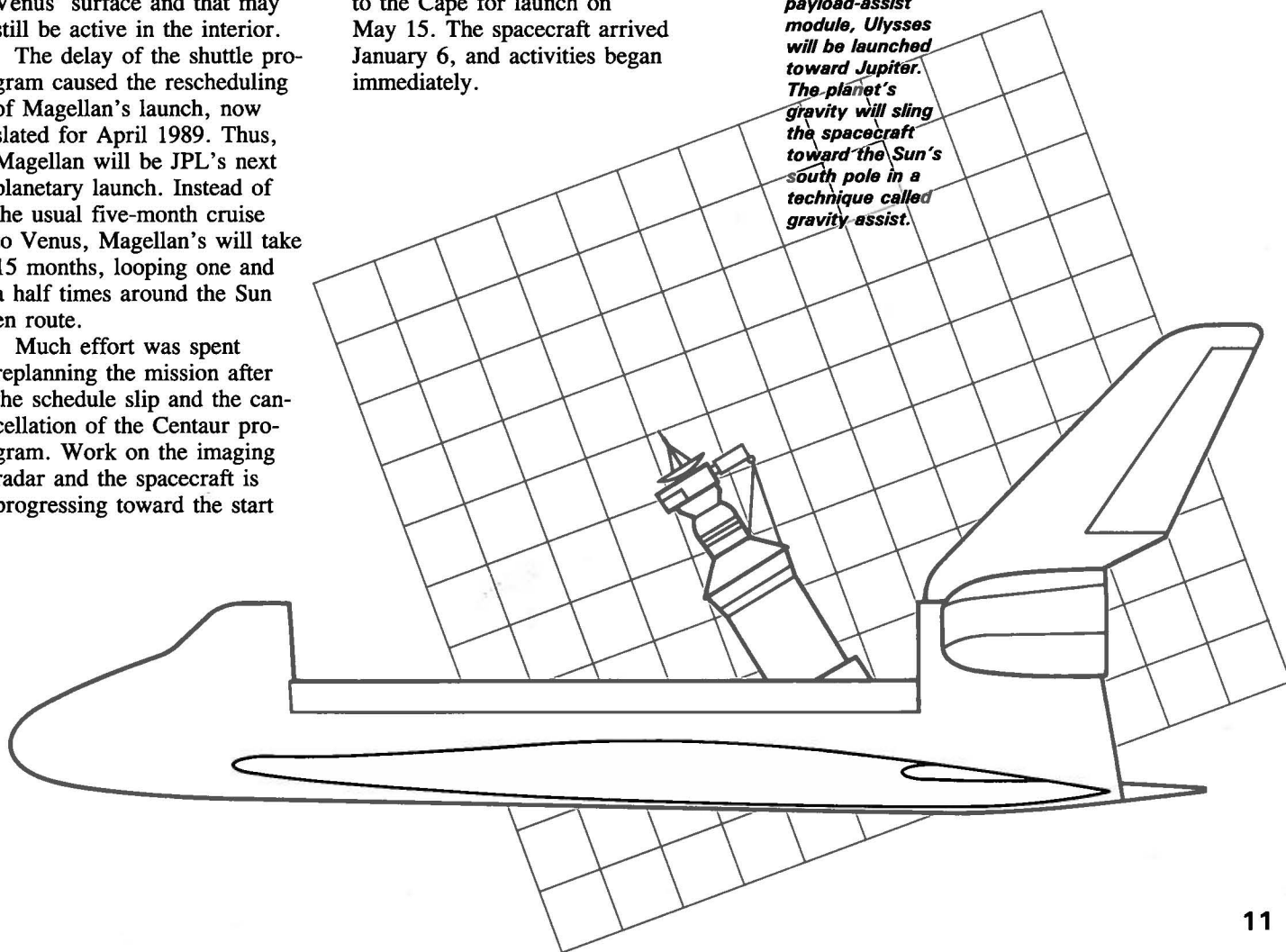
## ULYSSES

The Ulysses spacecraft was shipped from the European Space Research and Technology Center in the Netherlands to the Cape for launch on May 15. The spacecraft arrived January 6, and activities began immediately.

After the Challenger accident, a decision was made to complete stand-alone testing. When that testing ended, the spacecraft was stored at the Cape to await an early launch decision, which did not occur. When the 1989 launch date was determined, science instruments and the radioisotope thermal generator were returned to their respective U.S. agencies, and the spacecraft was returned to Europe for storage at the Dornier Systems plant in Friedrichshafen, West Germany.

*Magellan (opposite) will map most of the surface of Venus with an imaging radar. The mission will provide the first high-resolution maps of the surface of Venus, which is hidden beneath thick clouds.*

*Ulysses will be carried to Earth orbit in the cargo bay of a space shuttle (below). Atop an inertial upper stage and a payload-assist module, Ulysses will be launched toward Jupiter. The planet's gravity will sling the spacecraft toward the Sun's south pole in a technique called gravity assist.*



After NASA canceled the Centaur upper stage, the project studied several possible launch/upper stage options. The shuttle, with Boeing's inertial upper stage and McDonnell Douglas' payload assist module, was selected as the combination most nearly meeting the Centaur's capabilities. Launch-vehicle integration activities started late in the year with the Air Force Space Division supporting Marshall Space Flight Center and its contractors, Boeing and McDonnell Douglas.

The launch is planned for either September 1989 or October 1990, pending a final decision by NASA Headquarters.

## MARS OBSERVER

The Mars Observer flight project will study the surface and climate of Mars from orbit.

In March, RCA Astro-Electronics Division was selected to build the spacecraft, and Orbital Sciences Corporation to supply the upper stage. The spacecraft has a strong design heritage from the SATCOM-K communications satellite and from the TIROS/DMSP weather satellite.

In April, NASA selected eight instruments for Mars Observer. Five interdisciplinary investigations were also selected to exploit the synergism that exists among the instruments. Four instruments will observe in the infrared and visible regions, and two will explore with short radio waves. The Gamma Ray Spectrometer (GRS) will observe neutrons with energies up to 2.5 million electron volts.

A final instrument will search for and map the magnetic field of Mars. In November, the project recommended that the selections be confirmed.

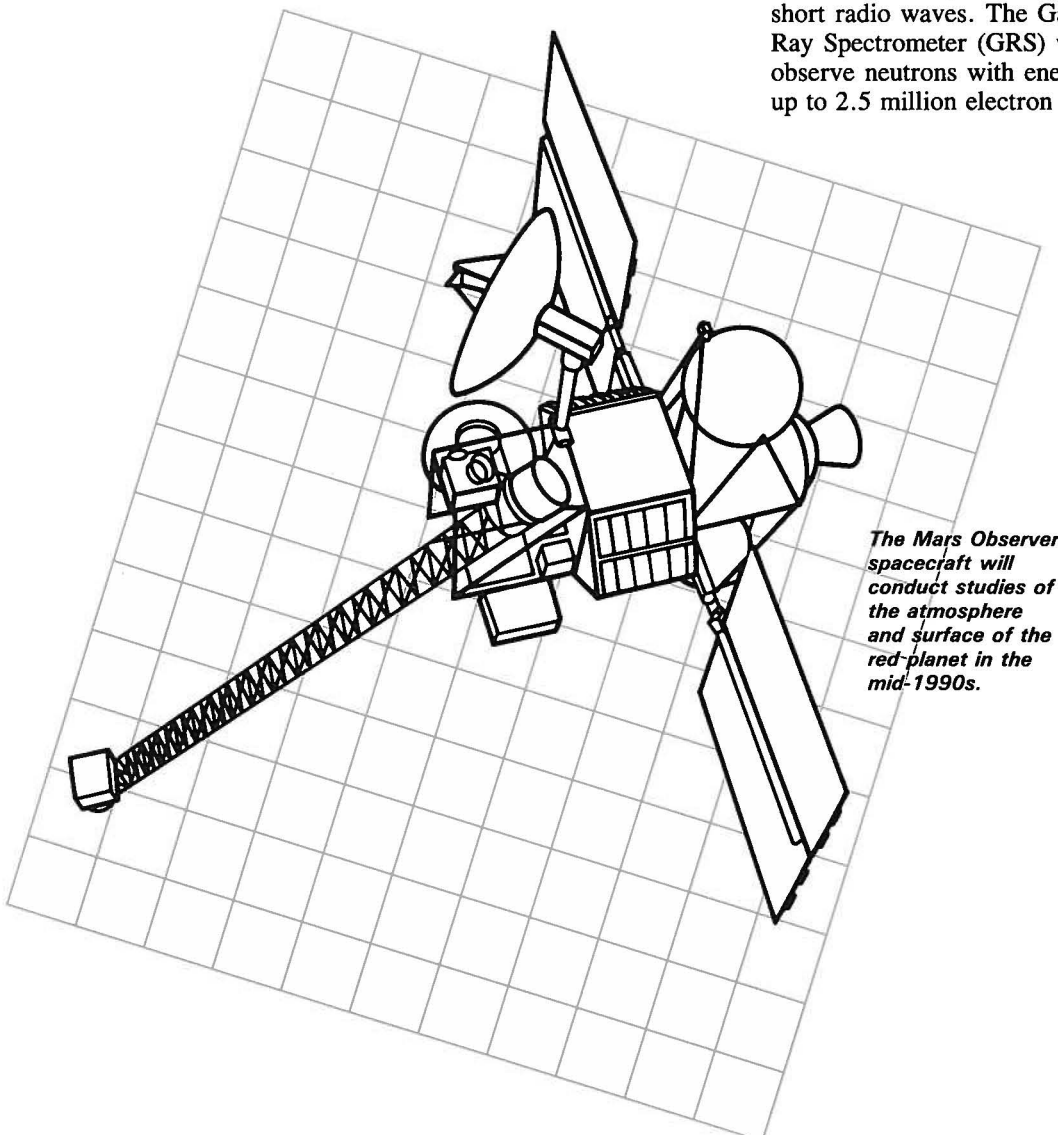
The mission's design continued to be refined. A significant change to the interplanetary phase added a midcruise trajectory-shaping maneuver, resulting in a 41.2-kilogram increase in on-orbit mass capability while maintaining a 687-day mapping mission in a nearly circular, low-altitude orbit.

## OCEAN TOPOGRAPHY EXPERIMENT

The Ocean Topography Experiment (TOPEX) received funding authorization as a 1987 new-start project. It will use altimeter measurements of the sea surface to map ocean circulation. The satellite will be launched, at the earliest, in late 1991 and is designed to be retrieved by a space shuttle.

The mission is collaborative with the Centre National d'Etudes Spatiales (CNES), the French space agency, which plans to perform ocean experiments. Called TOPEX/Poseidon, the joint mission will launch the satellite aboard a French Ariane booster. The satellite request for proposals was issued to three firms—Fairchild Industries, RCA Corporation, and Rockwell International—with a contractor to be selected in January 1987. Both NASA and CNES released Announcements of Opportunity seeking principal investigators. The investigators will be selected in September 1987. Also in 1986, JPL published the TOPEX/Poseidon Science Opportunities Document.

The performance of an advanced, two-channel altimeter is being evaluated, and a gravity-field program has produced an improved model of the Earth's gravity field.





## NASA SCATTEROMETER

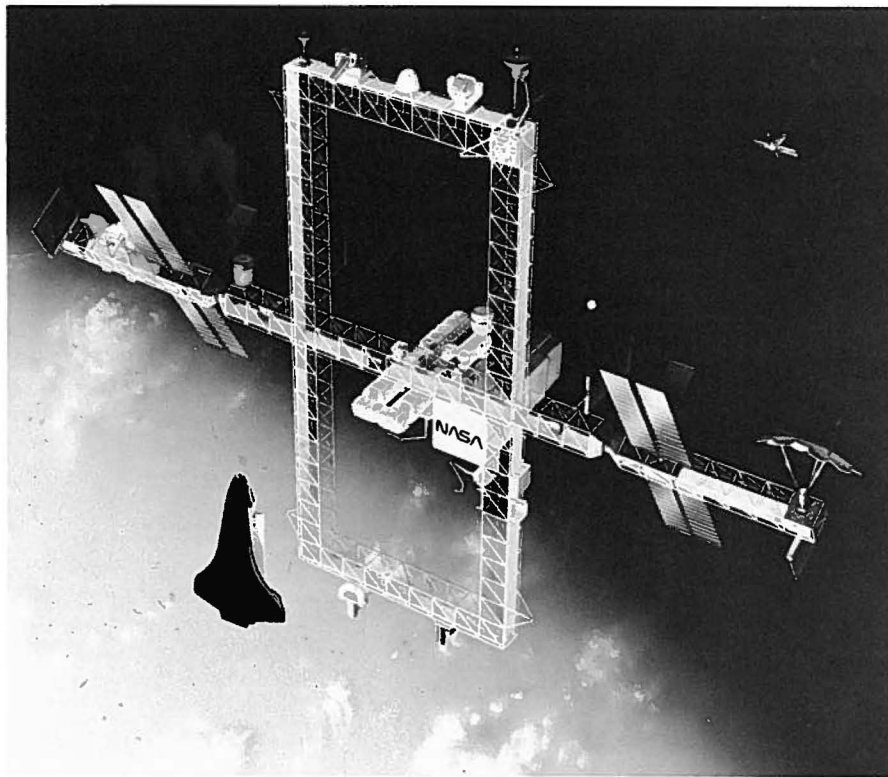
The NASA Scatterometer (NSCAT) project is developing a backscatter Ku-band radar and a ground data-processing system to produce frequent high-resolution measurements of near-surface winds over the global oceans.

Significant milestones were accomplished despite a 60 percent funding reduction caused by a 15-month delay in launching the Navy Remote Ocean Sensing System (N-ROSS) spacecraft that would have carried the instrument.

The budget restriction prevented the award of a single-source contract for the radio-frequency subsystem. Instead, one contractor was selected for the traveling-wave-tube (TWT) high-voltage power supply and a second for the balance of the radio-frequency (RF) electronics. Contracts are in place for the TWTs, antennas, high-voltage power supply, and RF electronics, and a contractor was selected for the instrument data-handling computer.

The architecture of the NSCAT ground data-processing system has been set. An algorithm-development test bed is nearly complete, and breadboard software has been developed to process raw data into sensor and geophysical data. The requirements for procuring the large data-processing computer are being developed.

At year's end, the Navy canceled N-ROSS, so NASA and JPL are exploring other launch opportunities, among them the Air Force's Defense Meteorological Satellite, the U.S. Department of Defense (DOD) Space Test Programs, and TOPEX/Poseidon.



*NASA's space station is expected to begin operations in the mid-1990s, establishing a permanent manned presence in space. JPL has a major involvement in the space station work for NASA. The painting here shows one of several possible designs for the space station.*

## EARTH OBSERVING SYSTEM

The Earth Observing System (EOS) program will encompass essentially all of the United States' Earth observations from orbit from the mid-1990s past the turn of the century. The concept of the system includes three large platforms in polar orbit and an integrated instrument set and ground network with NASA, the National Oceanic and Atmospheric Administration, and international participants.

In support of NASA's Office of Space Science and Applications and Goddard Space Flight Center, JPL continued to lead the definition of EOS flight elements. A key to implementing the EOS as it was conceived is the ability to service instruments on orbit. The JPL team began to study the technological and operational challenges associated with on-orbit instrument servicing.

## SPACE STATION

As 1986 ended, NASA's Space Station program prepared to begin development in summer 1987. As a result of NASA's reorganization after the Challenger accident, JPL was asked to take a larger role in the program. By the end of 1986, NASA and JPL were near agreement about a requirements-definition and assessment role for JPL at the program level.

In 1986 JPL continued emphasizing the use of the space station, focusing on engineering requirements associated with major space station payloads and classes of payloads and on the definition of policies, procedures, organizations, and systems to exploit the station's usefulness.



**W**e explore the solar system in our quest for scientific knowledge, and despite the setbacks caused by the Challenger accident, we learned much through space science during the year.

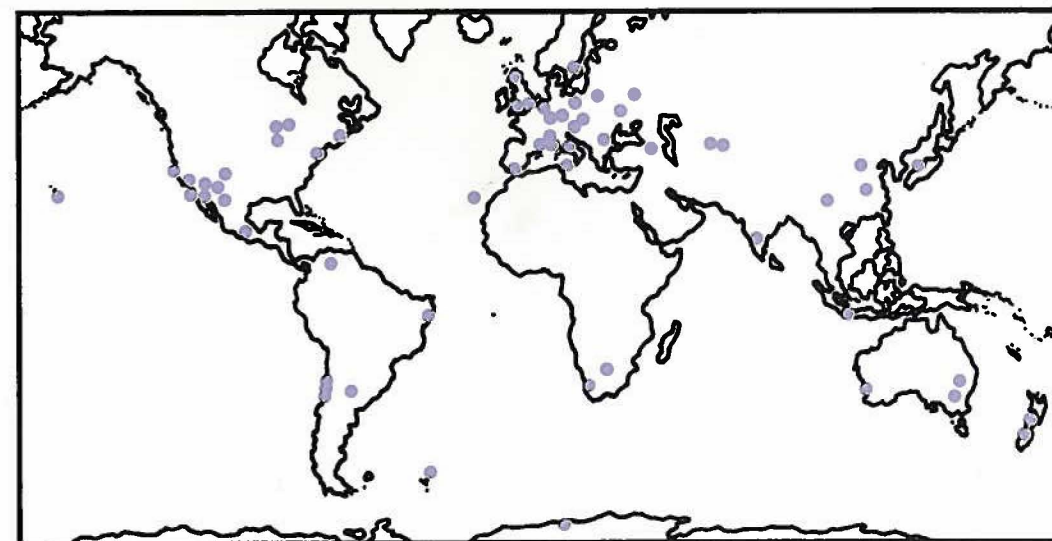
While some of the greatest additions to our knowledge came from Voyager's Uranus encounter, we also gained knowledge from the scientists who observed from Earth the other bodies of the solar system. Edmund Halley's comet passed our way once again, and JPL led a worldwide team of astronomers, both professional and amateur, in studying the comet and collecting and archiving the results. In addition, the Deep Space Network assisted other space-faring nations in their encounters with Halley.

#### INTERNATIONAL HALLEY WATCH

The International Halley Watch (IHW) was created to achieve the greatest scientific value from the collective, worldwide, ground-based observations of Comet Halley. But the IHW became closely tied to the spacecraft missions to Halley as well. Those missions depended on ground-based observations: astrometric positions for navigation, studies of Halley for hazard evaluation, and comprehensive, multiyear-long observations of all types to set their brief flybys in the context of the far larger data set.



*Halley's Comet, perhaps the most widely known of all celestial objects, was photographed by Alan Dressler and Rogier Windhorst with the 2.5-meter duPont reflector at Las Campanas Observatory in Chile on March 16.*



*A worldwide network of astronomical observatories (purple) cooperated in the Large-Scale Phenomena Network of the International Halley Watch.*

Eight IHW observing networks, differentiated by technique, enlisted more than 1,000 professional astronomers from 51 countries. More than 1,000 amateur astronomers worldwide also offered help. According to current logs, more than 1,000 astronomers participated. For every person who signed up but did not observe, there were one or two others who did not join but took data and have expressed their intent to contribute to the Halley Archive. In addition to Halley studies, several hundred astronomers also observed Comet Giacobini-Zinner, the target of the International Cometary Explorer mission in 1985.

Preliminary data logs were assembled by the discipline specialists who ran each observation network. The logs indicate there are more than 20 billion bytes of Halley data and 300 million bytes of Giacobini-Zinner data. As the final logs are completed, the numbers may double, even as Halley observations continue.

Meanwhile at JPL, the lead center of the IHW, work is under way on the archive, the final product of all the effort. It will contain ground-based and space results, while interpretations will appear in technical journals. To maintain the full digital accuracy of the

original data, the primary form of the archive will be a set of compact discs for release in mid-1990. Data tapes also will be a part of the new Planetary Data System being created by NASA to store all solar system data. Tapes will be sent to any country wishing to set up an archive.

Finally, there will be some form of hard-copy archive for use in countries where personal computers and disc readers are not ubiquitous. The original intent was to produce the hard-copy version as ordinary books. But such books would likely total 30,000 pages, so microfiche may be used instead.

The IHW and its archive of Halley and Giacobini-Zinner data are progressing as planned in 1980-81. If funding and cooperation continue as planned, 1990 should see the production of a cometary database of permanent value to solar system research.



## PLASMA MEASUREMENTS AT HALLEY'S COMET

The Giotto Ion Mass Spectrometer, a collaboration between JPL and European scientists, flew aboard Giotto to Halley's Comet. The spectrometer detected protons from Halley's Comet when it was 7.5 million kilometers away from the nucleus and in the tenuous hydrogen corona, and then it mapped the interactions of cometary ions with the solar wind until Giotto was 3,000 kilometers from Halley's nucleus. Then dust from the comet disturbed Giotto's electrical system, and the instrument quit working.

The spectrometer revealed that Halley's coma contained an unexpected abundance of carbon ions, from either dust grains or the dark surface. The instrument also mapped the distribution of ions from the breakdown and chemical reactions of water, methane, and carbon monoxide. Sulfur ions were abundant, but nitrogen-bearing molecules rare.

As Giotto flew through the coma, the ion mass spectrometer measured the interaction between Halley and the solar wind that may be responsible for the complex ion tails displayed by Halley and other comets. The instrument first detected a slowing and heating of the solar wind in the newly ionized cometary gases picked up by the solar wind. A bow shock was detected about 1 million kilometers upstream from the nucleus. Behind the shock, the plasma became slower, hotter, denser, and richer in comet material. Nearer, at 4,700 kilometers upstream, Giotto crossed a boundary between the nearly stagnant, magnetized mixture of both solar wind and cometary ions and the unmagnetized, almost purely cometary plasma flowing from the nucleus.

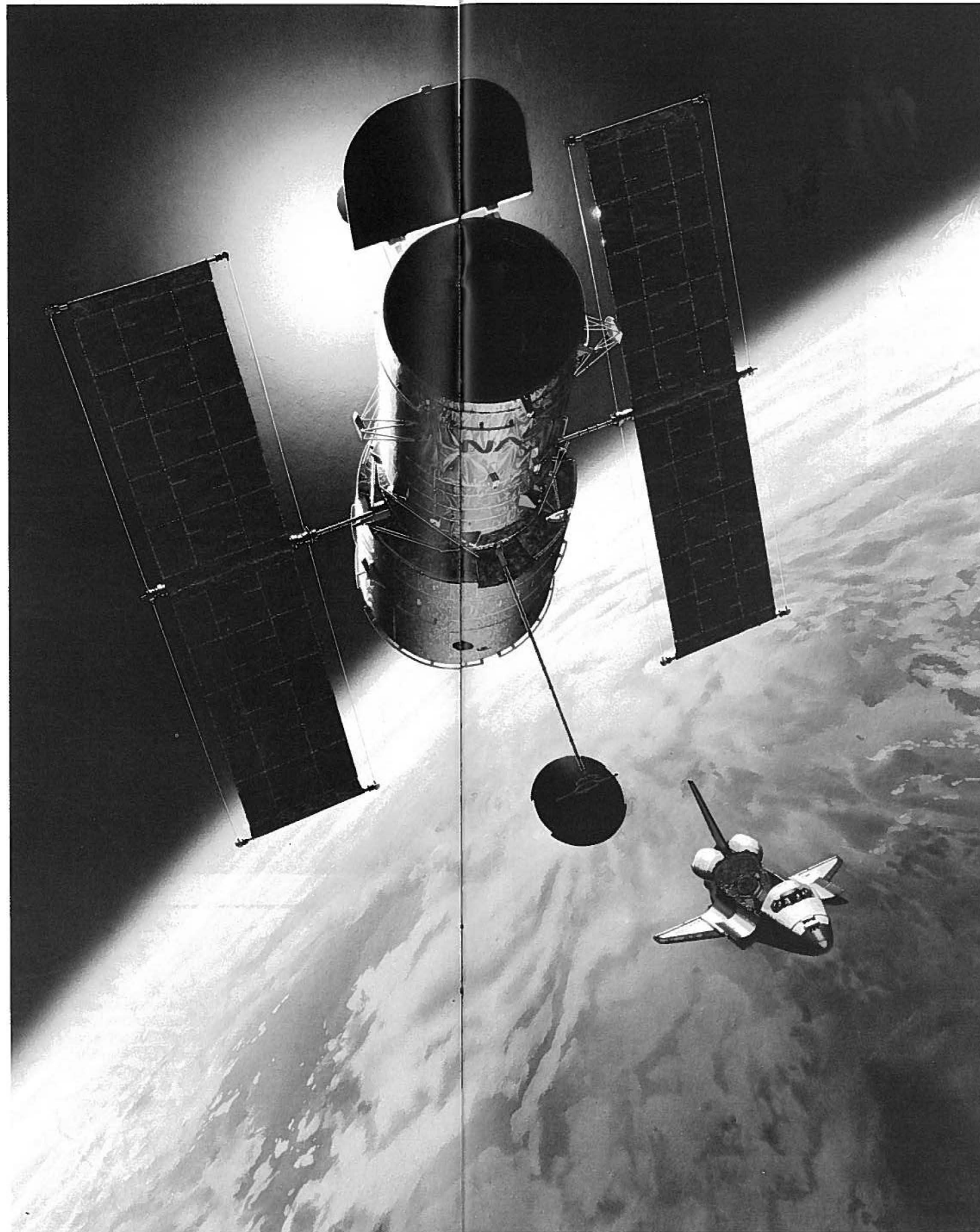
## ICE OBSERVATIONS AT GIACOBINI-ZINNER

On September 11, 1985, the International Cometary Explorer (ICE) encountered the comet P/Giacobini-Zinner. When 100,000 kilometers away, ICE crossed a bow wave accompanying the comet. Inside the bow wave, ICE found that the solar wind flow was dominated by heavy, hot, cometary ions. The spacecraft then penetrated the magnetic tail 8,000 kilometers from the nucleus of Giacobini-Zinner and traversed two magnetic lobes containing opposing magnetic fields that formed a barrier around the plasma tail of high-density, cool, cometary ions.

The spacecraft observed that the comet perturbed the oncoming solar wind over several million kilometers. Even at great distances upstream from the comet, cometary ions ( $H_2O^{++}$  group) were assimilated into the solar wind. The destabilizing effect gave rise to plasma waves at tens of kilohertz and to hydromagnetic turbulence near the gyro-frequency of the ions.

The structure of the comet's tail, as observed by ICE, was compared with Earth-based images made both before and after the encounter. Scientists found that the magnetic tail in the images corresponds to the plasma tail measured by ICE. Scientists also now know that the rotation of the solar wind's magnetic field causes the tail to twist so that it appears to vary in thickness when viewed perpendicular to the plasma sheet.

In addition, the spacecraft ICE returned information



useful to Halley studies. In April, ICE was upstream of Halley 30 million kilometers where it observed the incoming solar wind for a month while Earth-based observations were concentrated on Halley. The collected data can be used to relate the changes in the solar wind to the dynamics of Halley's tail.

## HUBBLE IMAGING MICHELSON SPECTROMETER

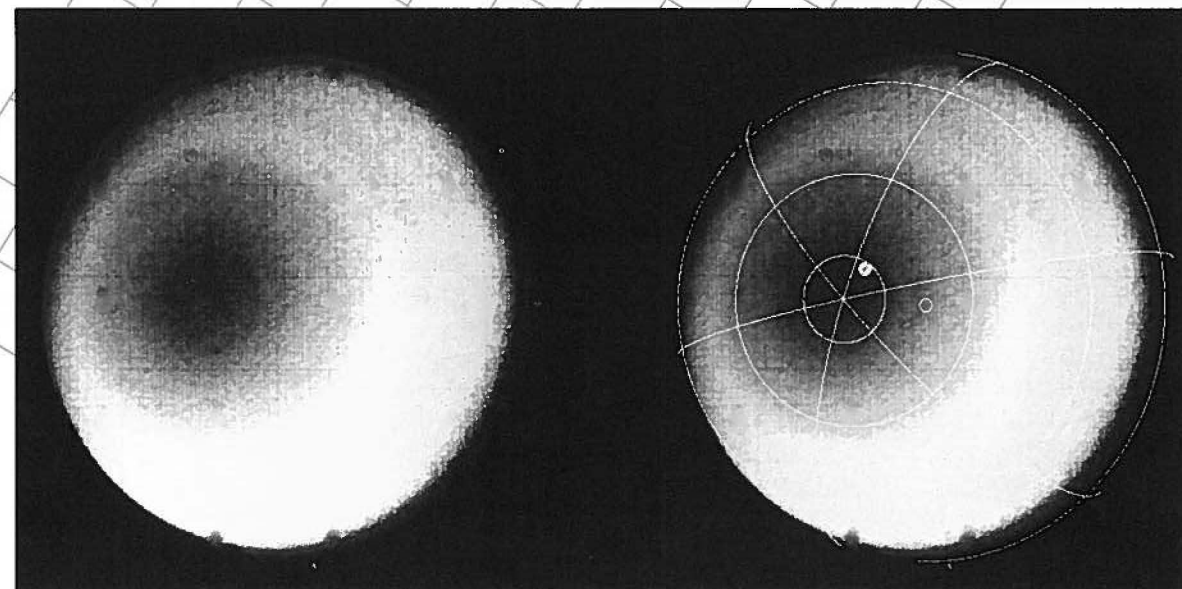
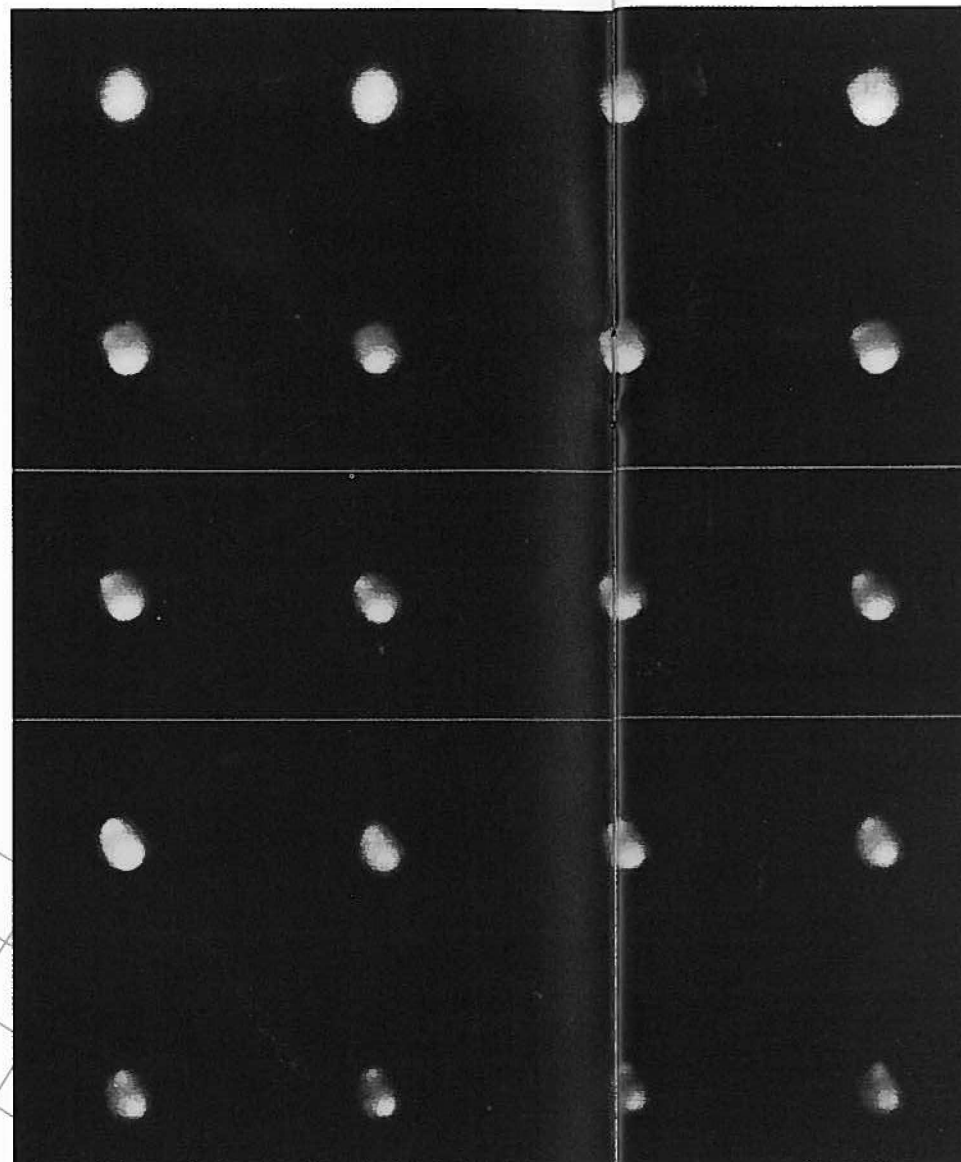
JPL is developing the Hubble Imaging Michelson Spectrometer (HIMS) as a second-generation instrument for the Hubble Space Telescope. The principal investigator is from the University of Hawaii, Institute for Astronomy.

The HIMS instrument will consist of two infrared array cameras mounted in the focal planes of the outputs of a Michelson interferometer. A field from the Hubble Space Telescope focal plane will be imaged onto each detector array. When the interferometer is stepped, corresponding pixels in the two arrays will record complementary interferograms. The signal from each pixel will be transmitted to the ground. The HIMS will produce two data cubes of interferograms at every point in the field.

The instrument is being designed for on-orbit emplacement. After the telescope is launched, HIMS and other second-generation instruments will be developed, built, and tested. Later in the 1990's the second-generation instruments will be taken to orbit by the space shuttle. Astronauts will remove the initial instruments and replace them with the new ones.

*NASA's Hubble Space Telescope, which will carry several JPL instruments during its lifetime, is expected to show phenomena in the universe that have never been seen with ground-based telescopes. In the painting, a shuttle closes on the telescope so that astronauts may perform periodic maintenance.*

Astronomers at JPL and the University of Arizona took these photographs of Neptune with the 2.5-meter duPont reflector at Las Campanas Observatory in Chile. The bright spots are atmospheric features that rotate with the planet, probably clouds of methane crystals elevated above Neptune's atmosphere.



Voyager photographs of Uranus (with a latitude and longitude grid superimposed at right) show the planet's atmosphere circulating in the same direction as the planet rotates.

## HYDROCARBONS IN THE STRATOSPHERES OF URANUS AND NEPTUNE

The atmospheres of Jupiter, Saturn, Uranus, and Neptune contain simple hydrocarbons. Now ground-based observations of Uranus and Neptune by a JPL astronomer have detected some of those hydrocarbons and have found that the atmospheres of Uranus and Neptune differ markedly.

The data show an inactive stratosphere at Uranus and an active one at Neptune. The data also contain the first indication of ethylene in the outer solar system—at Neptune—outside of a region near the magnetic north pole of Jupiter.

Uranus appears to have a spectrally continuous particulate haze emitting in the warm stratosphere. The haze adds to the radiation emitted by the deeper troposphere. Acetylene was detected but ethane was not, so little must be present. The astronomer had expected to see methane since its photochemical destruction creates the source material for acetylene, but methane's mixing ratio must be low. A picture emerges of a quiet stratosphere in which methane is not replenished quickly enough to offset photochemical depletion.

Neptune appears different. Methane is brought up through the cold trap so efficiently that its stratospheric mixing ratio appears to be the same as in the deeper atmosphere.

## AIRBORNE SUBMILLIMETER ASTRONOMY

The JPL dual-frequency submillimeter receiver flew again in May on NASA's Kuiper Airborne Observatory. The flights were made from Christchurch, New Zealand, because of the good viewing conditions for Comet Halley and for galactic objects visible only from the Southern Hemisphere's sky. Five-hour astronomy flights were carried out on May 6 and 7 with the receiver on the 91.5-centimeter-diameter telescope. On five

engineering flights, the receiver viewed the atmosphere through a fuselage window. During the engineering flights, nitrous oxide ( $N_2O$ ) was detected in the stratosphere, and line profiles of water ( $H_2O$ ) and oxygen ( $O_2$ ) were measured. The May 7 flight was to search for water and a deuterated hydrogen radical in dense interstellar clouds. Earlier observations had established that the giant molecular cloud core in Orion is a strong emitter in the 183-gigahertz water transition. The new data indicate that the emission has diminished in a year to about 10 percent of its 1985 value. The observations also resulted in the detection of water at 183 gigahertz in at least two other molecular clouds. The observations triple the number of known molecular clouds that emit at that transition.



**S**tudies of the ever-changing planet on which we live continued in 1986 with several important discoveries. We made new measurements, with new accuracy, of the Earth's moving surface plates and new measurements of the ways human activities modify our planet.

#### PLATE TECTONICS

JPL's research to measure the movement of tectonic plates on the Earth's surface entered a second phase. The initial phase had used mobile microwave antennas and very long baseline interferometry to make baseline measurements. Then this year, researchers used satellites of the Global Positioning System (GPS) and GPS geodetic receivers to extend the baseline measurements from Southern California into the northern Caribbean. The measurements will provide data for analyses of active seismic zones associated with tectonic plate motions and earthquake activity.

A key element of JPL's effort is the development of an advanced geodetic receiver to support the studies of tectonic plate movement around the North American continent. The current accuracy for existing receivers is a few parts in ten million. The accuracy can be improved by an order of magnitude with the development and verification of the receiver.

*The San Andreas Fault, a major phenomenon of plate-tectonics activity, cuts across the Los Angeles region (toward the top) in this space photograph. The fault is the border between the North American plate (top) and the Pacific Plate on which Los Angeles sits. Catalina Island is at the bottom of the photograph.*



Participating universities and government agencies include the National Oceanic and Atmospheric Administration; U.S. Geological Survey; Oregon State University; University of California, San Diego; Woods Hole Oceanographic Institution; and a consortium of Caltech, Massachusetts Institute of Technology, University of Colorado, University of Texas at Austin, Columbia University, Harvard, and Princeton.

#### GOLDSTONE SOLAR SYSTEM RADAR

The Goldstone Solar System Radar observed the following:

- ☆ Mercury, through inferior conjunctions in March, July, and November. Two types of data were obtained: (1) interferometric data for imaging and (2) ongoing relativity data. The first X-band ranging data were obtained in November.
- ☆ Venus during inferior conjunction from September through December. The three-station interferometric observation yielded the highest resolution (1.5 kilometers) images of Venus of any Earth-based radar.
- ☆ The newly discovered Apollo-class asteroid 1986JK, detected in May, three weeks after its optical discovery. In addition to defining the physical properties of 1986JK, the data yield precise (one part in a hundred thousand) measurements of its line-of-sight velocity. Such knowledge should ensure the optical recovery of the asteroid during its next close approach to the Earth in 1995.
- ☆ The Saturnian satellite Titan, observed for 13 nights in May and June.
- ☆ Mars during the long opposition period from July through October.

#### SPECTRAL SENSING OF VEGETATION DAMAGE

JPL used remote sensing and ground-based techniques to measure forest damage in a pilot study of four sites for the National Acid Precipitation Assessment Program. Landsat Thematic Mapper data were used to assess, map, and compare the damage at each site.

The results indicate that the differences in spectral signatures correlate closely with the levels of healthy living specimens and dead timber characterizing forest stands. A JPL index has been used with Thematic Mapper data to locate fir waves (alternating stands of healthy and dead trees), damaged stands, and healthy conifer forests on Whiteface Mountain, New York.

#### CZCS IMAGERY FROM THE WEST COAST OF NORTH AMERICA

A seven-year time series of phytoplankton pigment images was created using data from the Coastal Zone Color Scanner (CZCS) on Nimbus-7. The series of 885 images covers most of the west coast of North America from mid-1979 to mid-1986. The analysis focused on large offshore filaments that often extend several hundred kilometers from the coast.

Although the series is biased toward periods of high equatorward winds, simple statistical analyses reveal several points about the features. First, filaments are apparent in CZCS imagery from about mid-March until mid-October, which corresponds to the upwelling season. Second, the features



tend to recur at specific coastal headlands. Third, the filament lengths are variable, although there appears to be a rough relationship between filament length and the strength of the equatorward winds. Fourth, there is some interannual variability, again apparently reflecting changes in wind stress. Fifth, filaments tend to be most common off central California and Baja California, although during strong winds, filaments are visible off British Columbia, Washington, and Oregon. Sixth, the orientation of the filaments is surprisingly constant over time.

The recurrence of the filaments at headlands and their variability as a function of wind conditions suggest that coastal topography and winds are the driving forces in the formation and maintenance of the filaments. The features may be important in the exchange of productive coastal water with less-productive oceanic water.

## SEASAT WINDS

Recent analysis of data from the SEASAT satellite has resulted in a wealth of new information about the oceans. One SEASAT instrument, the scatterometer, measured surface wind speeds and directions over the oceans, regions covering about 70 percent of the Earth's surface. Though crucial to the redistribution of heat and moisture in the atmosphere, the seas are poorly understood because they are difficult to observe on a large scale. Global wind data obtained from the analysis of SEASAT's scatterometer data now provide a look at the dynamics of climate and weather with unprecedented detail.

A high-quality, 15-day data set of high-density wind measurements allows scientists to identify and clarify the atmospheric flow patterns in previously data-poor areas, to conduct high-resolution studies of the structure and evolution of explosive storms and hurricanes, and to analyze wind stress and its driving force on waves and currents. Future studies will incorporate high-density satellite wind measurements into numerical weather-forecasting models, a crucial step in developing weather-forecasting skills and in preparing missions that will involve ocean wind measurements.

## MODELING POLLUTION EFFECTS ON VISIBILITY

The visibility problem caused by smog in Los Angeles is serious. To design air-pollution-abatement programs that improve the situation, a method must be found to predict how altering the air-pollution profile will affect visibility.

Combining Caltech's visibility models and JPL's image-processing capabilities has resulted in a model that will predict how visibility changes in response to various atmospheric-loading profiles. The potential applications range from assessing air-pollution-control strategies for automobiles to evaluating changes in visibility in protected areas where energy developments are allowed.

## MULTISENSOR IMAGES

Earth scientists at JPL have developed methods to combine data sets from multiple sensors to capitalize on the synergistic information provided by different regions of the electromagnetic spectrum. The resulting multisensor images enable scientists to infer chemical and physical properties of the Earth's surfaces.

For example, combining SEASAT Synthetic Aperture Radar (SAR) data with certain Thematic Mapper data and

with digital terrain data helps quaternary geologists to determine the relative ages of some of the Earth's surface, information from which past climate changes can be inferred. In addition, the incorporation of the digital terrain data makes it possible to generate perspective views, which help geologists to make structural interpretations. Thus, the analysis of such different kinds of data sets enables scientists to infer both climatic and tectonic information on a regional basis.

## BALLOON INFRARED DIODE LASER SPECTROMETER

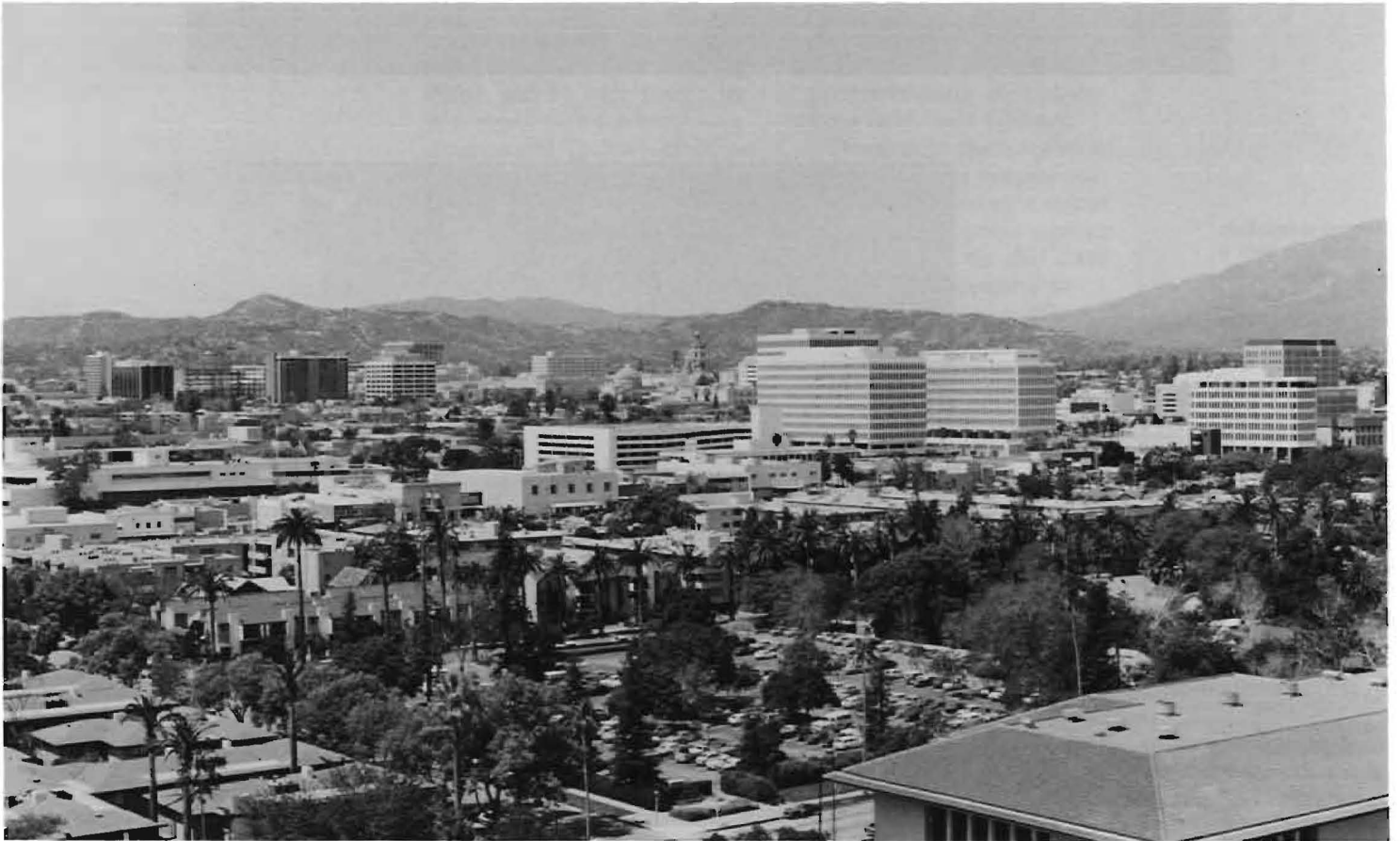
To more precisely assess the extent to which human activity modifies the ozone layer of the stratosphere, upper atmospheric studies use a new strategy for collecting data that requires the simultaneous measurement of several chemically related species, including ozone.

The Balloon-borne Laser In Situ Sensor (BLISS) uses the new approach to measure the composition of the stratosphere. At float altitude, about 35 kilometers, a visible laser beam optically tracks a retro-reflector lowered 500 meters below the instrument gondola. Light from tunable solid-state diode lasers is bounced off the retroreflector so that gas concentrations in the 500 meters of atmosphere between the laser and the retroreflector can be measured at the sub-parts-per-billion level.

The new spectrometer was flown in October and measured nitric oxide, nitrogen dioxide, nitric acid, ozone, water vapor, methane, and carbon dioxide. The instrument can measure other gases that are coupled to the depletion of stratospheric ozone.

A miniature version of BLISS is being designed as a candidate for the probe of the Cassini mission in the 1990s to study the organic chemistry of Titan's atmosphere.

*The Southern California area's infamous smog causes serious visibility problems. JPL scientists are working to predict how altering the air-pollution profile will affect visibility. The upper photograph shows a clear day at Caltech in Pasadena. The photograph was scanned into a computer and was digitized. The digitized data were then altered according to computer models of smog to produce the image below.*





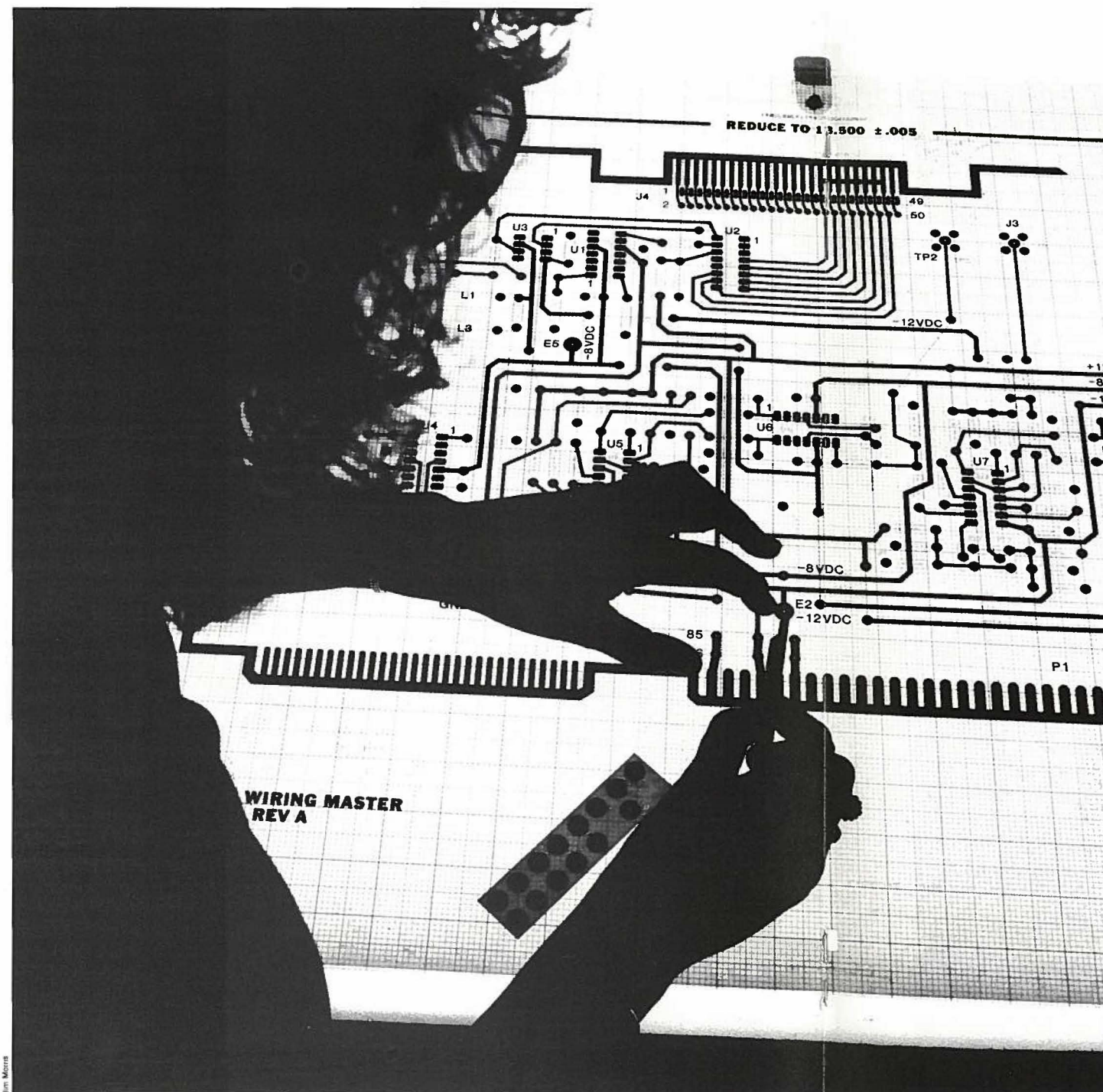
The Laboratory emphasizes the development and exploitation of advanced technology to support future missions. Advanced technology consists of applied research leading to new methods, techniques, processes, materials, or devices.

JPL focuses on certain advanced-technology programs as it pursues a position of national leadership. Current efforts are the Advanced Microelectronics Program (AMP) and the Automation and Robotics Program (A&RP).

**ADVANCED  
MICROELECTRONICS  
PROGRAM**

The Advanced Microelectronics Program is a JPL applied-research program, on which Caltech research faculty collaborate, in four areas: solid-state devices, optoelectronics, computer architecture and subsystems, and custom microcircuits. The goal of AMP is to develop advanced microelectronic concepts and devices supporting NASA and DOD missions and making the Laboratory a center of excellence in the field.

Highlights of AMP activities include the design and engineering of the Microdevices Laboratory. It will be a state-of-the-art facility for developing new solid-state devices. Groundbreaking is due in early 1987 and occupancy about 15 months later.



***A designer prepares a wiring master diagram for a new printed circuit board. When the board is completed and all the electronics secured to it, the board will be used in ground-support equipment for the Deep Space Network.***

Eight new research tasks within AMP were funded by the Director's Discretionary Fund, and 14 were funded by a contract with the Innovative Science and Technology Directorate of the Strategic Defense Initiative. Eighteen Caltech faculty members are collaborating with JPL on the program's research tasks.

## Hypercube

The Hypercube project continues as the leading concurrent-computation-research effort. Four firms are marketing Hypercube computers based on JPL's technology. About 100 have been sold.

The Mark III Hypercube was put into operation in May. Each of its nodes has the power of 1.7 VAX 11/780 minicomputers, and a 32-node Mark III has the computing power of a Cray XMP 1-1. The project plans to connect up to 256 nodes to form the world's most powerful general-purpose computer. In addition to designing hardware, the project has completed more than 40 applications programs through the Campus-Laboratory user group. The programs cover a range of scientific and engineering computational problems.

## Artificial Neural Systems

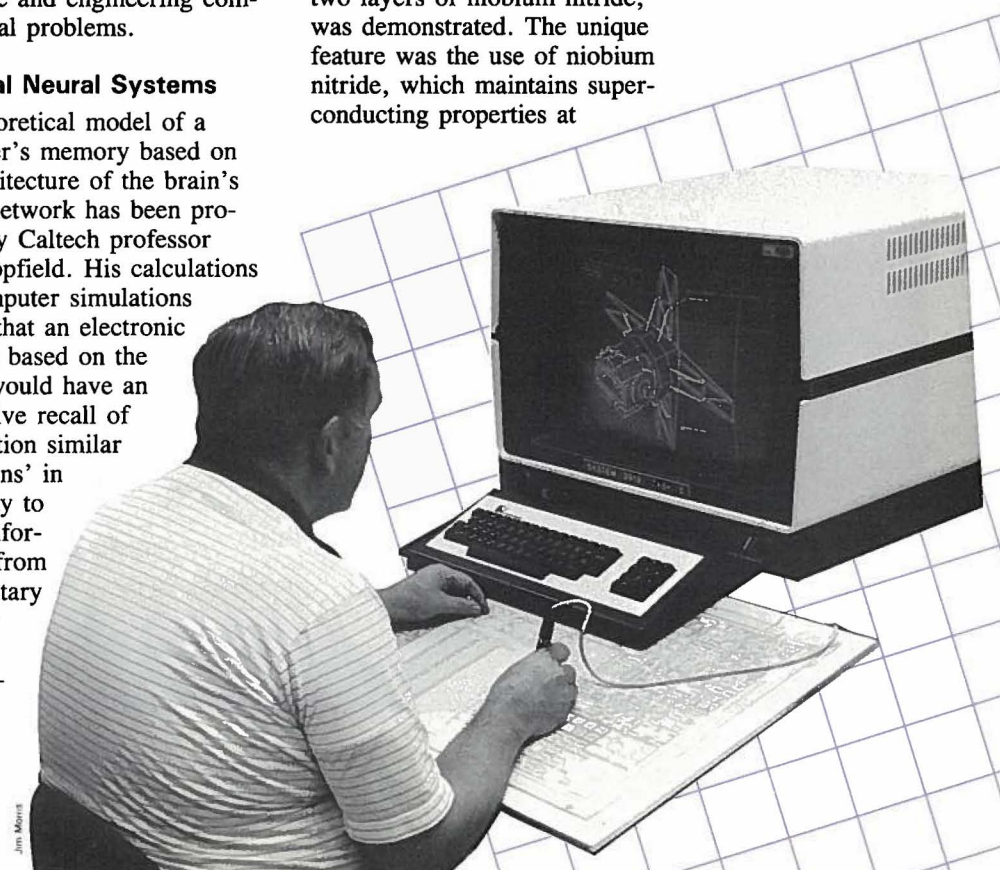
A theoretical model of a computer's memory based on the architecture of the brain's neural network has been proposed by Caltech professor John Hopfield. His calculations and computer simulations predict that an electronic network based on the model would have an associative recall of information similar to humans' in its ability to recall information from fragmentary clues or garbled information.

The artificial neural systems should retrieve stored information reliably when up to ten percent of their interconnections have been damaged.

Progress in the research of artificial neural systems has included fabricating a circuit embodying Hopfield's principles. Work at the chip level will allow researchers to experiment with specific applications of artificial neural systems to space-related computing systems. JPL researchers have also discovered that amorphous silicon can be used to fabricate a neural-like system that can electronically receive and store information.

## Solid-State Devices

Earth's atmosphere is opaque in the submillimeter band, so astronomical observations in that region are impossible near sea level. Because a submillimeter telescope in orbit could open a window on molecular astronomical processes, AMP is developing low-noise, ultrasensitive, superconducting-insulating-superconducting mixers. The first mixer, based on a 20-angstrom-thick layer of magnesium oxide between two layers of niobium nitride, was demonstrated. The unique feature was the use of niobium nitride, which maintains superconducting properties at



**An engineer (below) works on a CAD-CAM design for the Pathfinder spacecraft. Computer-aided design and computer-aided manufacturing are promising tools for future spacecraft development.**





15 kelvins and maintains chemical stability. That allows the detector to be used up to frequencies of 1,500 gigahertz without liquid cryogenes.

A newly emerging field in solid-state-device research is based on superlattice materials consisting of many thin parallel layers of semiconductor solids deposited in an *A B A B* alternating sequence. By varying the chemical species and thicknesses of *A* and *B*, engineers can design the composite material with the electronic and optical properties necessary for specific device applications. For example, a unique superlattice of indium arsenide/gallium arsenide has been developed that should enable a device to electronically modulate a beam of light. The device could also have applications in optical communication or computing. Superlattice materials will also improve infrared focal plane imaging devices for space instruments.

JPL also began operating a new microscope based on the quantum mechanical phenomenon of tunneling. The scanning tunneling microscope (STM) magnifies up to 100 million times. So great is its power that individual atoms can be seen. AMP plans to exploit the new technology to improve the quality and reliability of microelectronic devices, especially in ultrasensitive space instruments.

*An engineer works on the Hypercube, which is being developed at JPL with strong Campus participation. The Hypercube continues as the world's leading concurrent-computation research effort.*

### Devices for Long-Life Cryocooling in Space

Two devices using gas adsorption and desorption processes were developed to prolong the life of infrared sensors in space: nonmechanical heat switches for redundant cryocoolers, and a long-life, gas-sorption Joule-Thomson cryocooler for 4-kelvin cooling.

The life of any far-infrared sensor on a spacecraft is limited by the cryocooler but can be extended by using redundant cryocoolers. Such redundancy requires the thermal isolation of each stage of an inactive redundant cryocooler from the optical system, while each stage of the active cryocooler must be thermally connected.

JPL's novel design for a nonmechanical gas-gap heat switch avoids the problems of mechanical switching between cryocoolers. The heat switch consists of two concentric, close-fitting copper cylinders. When gas is present in the gap between the cylinders, heat is transferred from one cylinder to the other and the switch is *on*. When gas is removed from the gap, the cylinders are thermally isolated and the switch is *off*. Gas is controlled by a nonmechanical gas adsorption pump, which adsorbs gas at low temperatures and liberates it at high temperatures.

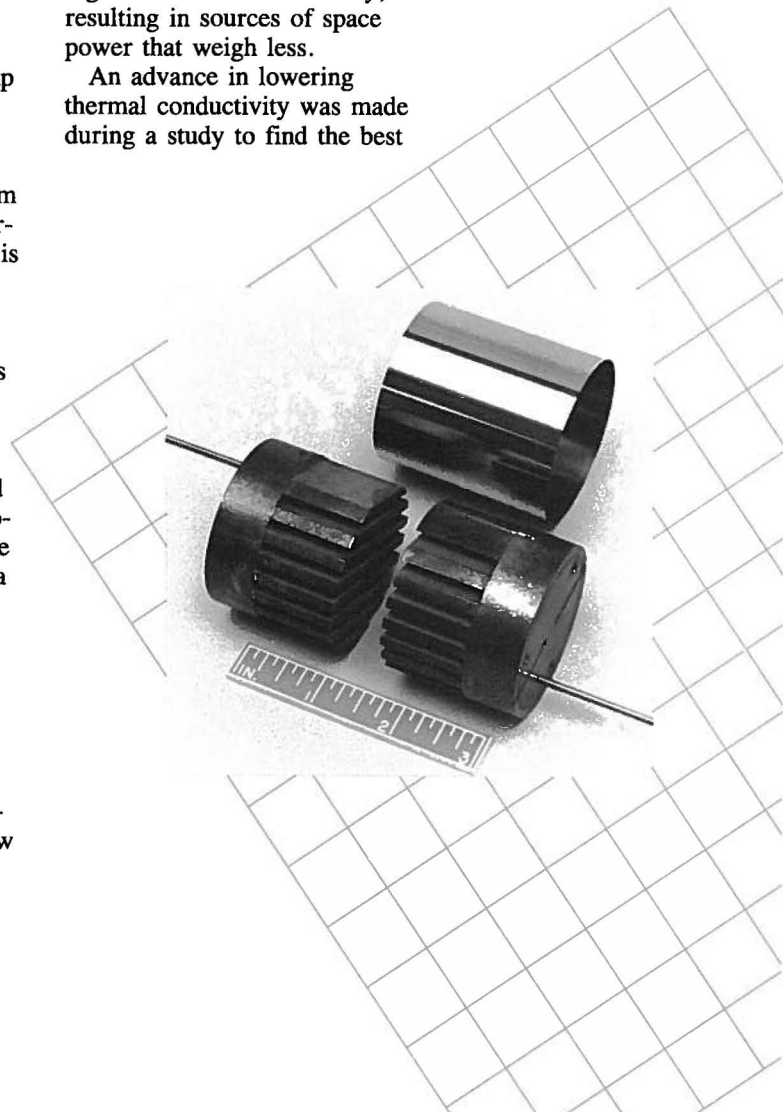
Another way to extend the life of a cryocooler is to eliminate its moving parts and seals because mechanical cryocoolers have a life of only one to two years. JPL developed a device that uses sorption materials for gas compression through a Joule-Thomson valve that requires no moving parts and that is powered by waste heat. The objective of the development is to demonstrate a gas sorption refrigerator that provides cooling below 10 kelvins.

### Advanced Thermoelectric Materials Technology

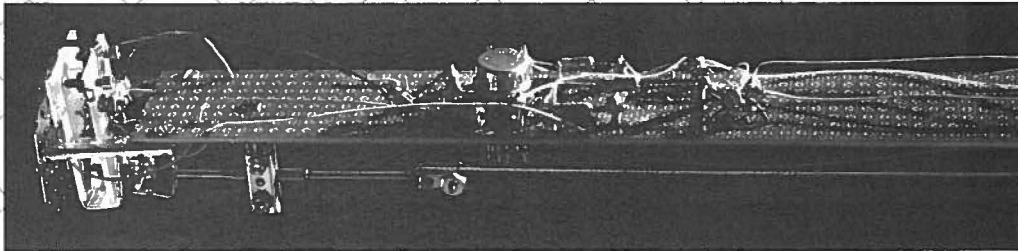
On the basis of research into the properties of silicon germanium thermoelectric alloys, scientists are developing semiconductor materials with thermal-to-electric conversion efficiencies that are two to four times better than with today's materials. Scientists are conducting laboratory experiments to understand the charge-carrier transport and thermal transport processes in solids with low thermal conductivity. The principles learned from the experiments—for example, reducing thermal conductivity increases the efficiency of conversion—are then applied to candidate refractory materials. The breakthrough, which has been eluding researchers now for a decade, will lead to a thermoelectric material with a 50-percent higher conversion efficiency, resulting in sources of space power that weigh less.

An advance in lowering thermal conductivity was made during a study to find the best

*The multifinned heat switch (below) offers to increase the life-time of cryogenically cooled space sensors.*







*The scanning tunneling microscope magnifies an object up to a hundred million times its actual size and has the ability to reveal individual atoms. It will be used to improve the quality and reliability of microelectronics devices.*

ratio of the chemical elements necessary to exploit the power of lanthanum telluride. Scientists discovered that the figure of merit of thermoelectric materials can be improved by introducing a second phase. The appearance of lanthanum oxytelluride as a second phase was studied, with photomicrographic and property-measurement data leading to a method that applies to most thermoelectric materials: Each chemical category of a substance should have the unique requirements necessary to achieve a proper second-phase composition and distribution. Exploiting the second-phase characteristic will produce thermoelectric materials with superior conversion efficiency.

### **A Xenon Ion-Propulsion Module for Spacecraft**

The ion engine is the most efficient electric propulsion engine and can attain the highest levels of specific impulse. That makes ion propulsion desirable for planetary missions requiring large velocity changes and for Earth-orbital and lunar-ferry missions, where large payloads are needed without the high costs of lifting enormous amounts of chemical propellant to low Earth orbit.

The assembled, two-engine, xenon ion-propulsion module includes two 30-centimeter, engineering-model xenon ion engines and a central neutralizer subsystem. Both engines and the neutralizer are mounted to a gimbal system that has independent articulation along two of the axes of each engine. The gimbal system is attached to the system for propellant storage, distribution, and control. The neutralizer consists of two hollow cathode neutralizers. Only one cathode neutralizer is used during normal

operation, providing neutralizing electrons for both engines. The other is a backup.

During the development of the module, several major accomplishments were made:

- ☆ A novel, highly reliable, advanced xenon-propellant high-voltage isolator was developed and demonstrated.
- ☆ A central neutralizer subsystem was developed.
- ☆ The maximum input power per engine was increased from 2.7 to 5.0 kilowatts.
- ☆ A xenon gas storage, distribution, and control system was designed and assembled.

Incorporating those features into the module resulted in a relatively simple, reliable, yet advanced propulsion system. The expertise gained from developing the ion-propulsion module should reduce the development time and the cost for flight hardware.

### **SHAPES: the Spatial, High-Accuracy, Position-Encoding Sensor**

Controlling large space structures requires knowing the precise location of many points on their flexible structures. The Spatial, High-Accuracy, Position-Encoding Sensor (SHAPES) is a control sensor that simultaneously measures the three-dimensional position of up to 50 targets with sub-millimeter accuracy. The three-dimensional measurement is made by combining optical angle and time-of-flight range measurements. SHAPES can be used to identify systems, to measure the shape and vibration of large space structures, and to point large space and Deep Space Network ground antennas.

A key event in the sensor's development was a demonstration this year of the simultaneous optical ranging of eight independent, moving targets.

The data update rate was 10 measurements a second, and range resolution was 10 micrometers.

In the multitarget-ranging demonstrations, retroreflector targets were mounted on a 4-meter-diameter support structure designed to simulate an antenna. The target motion was provided by mounting reflectors on either a free-swinging pendulum or a motor-driven actuator. The targets were illuminated with 30-picosecond laser pulses, and the range was determined by time-of-flight correlations with a streak-tube camera. A charge-coupled device (CCD) detector was the streak-tube readout device, and data were displayed as plots of target motion.

The main characteristic of SHAPES is that it can track many targets with great precision at a data rate high enough for many control needs. For example, such tracking capability is required to determine static and dynamic in-flight characteristics of large antennas, platforms, and the space station during both assembly and operation. During assembly, the measurements would be used to verify assembly and alignment. After assembly, the data would be used to collect in-flight structural dynamics data verifying the accuracy of modeled attitude-control systems. Other space-station applications might include the determination of payload pointing and alignment relative to navigational base information and a SHAPES derivative that could be used as a rendezvous and docking sensor.

Results so far have demonstrated the multipulse, multi-target, optimal-ranging concept. The next phase of development will include target measurements, via a second CCD, to obtain full three-dimensional measurements.

### Charge-Coupled Device for Astronomical Sensing

Two JPL engineers developed a technique to extend the spectral response and efficiency of CCD imaging systems, a significant technical development in their design. The invention follows an earlier invention by the same two engineers for which each received a NASA award of \$5,000. The new CCD technology will be used on the Hubble Space Telescope's second-generation Wide Field/Planetary Camera.

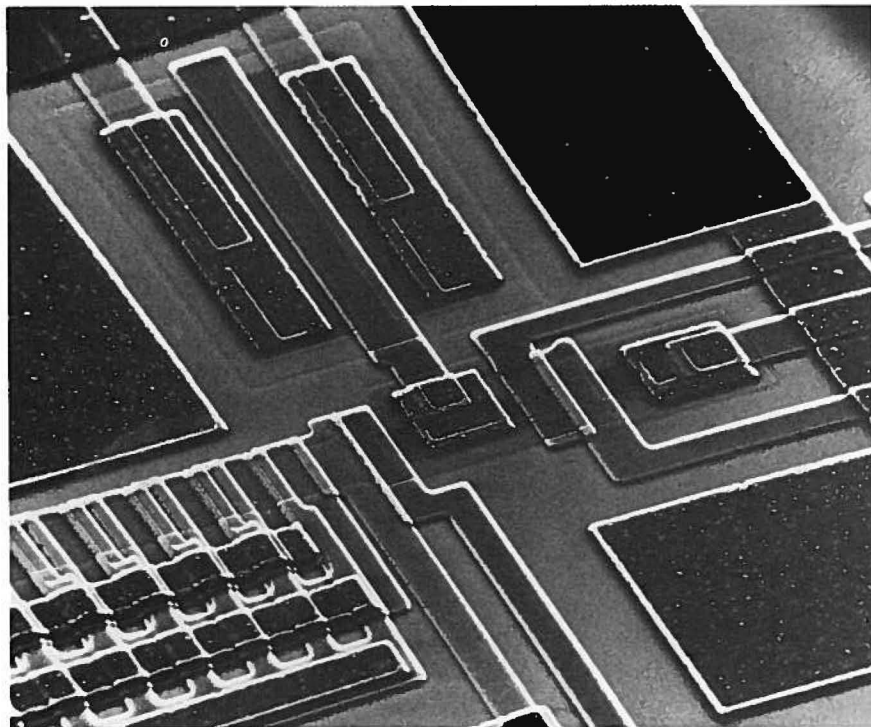
The design modifications allow cameras to be used in the ultraviolet, extreme ultraviolet, and soft X-ray regions of the spectrum. The engineers found a technique that permanently corrects the sensitivity-instability problem of CCDs and provides good sensitivity into the soft X-ray spectral region. Based on a process of spreading a one-atom-thick layer of platinum over the CCD surface, the new technology achieves the same effect, charge stability, as with back-side solar ultraviolet charging.

### Space Reactor Power System Project

JPL is the Project Office for the SP-100 project to develop the technology for a multihundred-kilowatt-class space nuclear power system for the mid-1990s and beyond. The project involves three agencies, the DOD, U.S. Department of Energy, and NASA.

In 1986 the project completed the first year of a six-year ground engineering system phase to address the development and testing of a reactor, a power-conversion system, and components. The phase is designed to demonstrate the readiness of the technology by providing analysis, hardware, test data, and experience in designing, building, and operating components, assemblies, and subsystems. The subsystems for the ground-engineering reactor, heat-transport loop, power conversion, heat rejection, power conditioning, and controls will all be tested along with an electrically heated reactor in a simulated space environment.

*In this picture, the support structure of a CCD was magnified several hundred times by a scanning electron microscope. Eight of these three-phase CCDs will be used in the second-generation Hubble Space Telescope's Wide-Field/Planetary Camera.*





General Electric Corporation was chosen to design, build, and direct the ground-demonstration test of a compact 300-kilowatt (electric) power system using thermoelectric energy conversion. The contract will involve 20 sub-system and component subcontractors.

Three thermoelectric technology contracts were awarded in 1986. They will continue to advance the state of the art in developing the materials and the converter.

#### Advanced Digital SAR Processor

The Advanced Digital SAR Processor (ADSP) task began in 1982 to develop technology for future Synthetic Aperture Radar (SAR) missions. At that time, only commercially available equipment could perform the vast number of computations required for SAR processing, and that equipment operated hundreds of times more slowly than the data were acquired. As an example,



Several images taken by the synthetic-aperture radar aboard SEASAT have been combined in this mosaic (above) of the Southern California coastal region. Such radar mosaics help scientists study large-scale geologic features. The technique can also be used to map regions that are frequently covered by clouds.

the 50 hours of SAR data from SEASAT would have taken about ten years to process with the equipment available at the time.

The original ADSP goal was to increase computing speed by about 100 times and build an engineering model having one-quarter real-time capability for a SEASAT-class SAR mission. The approach was to use existing integrated-circuit technology for a proven SAR processing algorithm with custom-designed digital circuits in a pipeline architecture.

During the development, integrated-circuit technology improved substantially, and designers incorporated the latest circuits. Tests performed in July 1986 were followed by a system demonstration in August. Data from the Shuttle Imaging Radar B were input from a high-density tape recorder at 45 million bits per second, which was 1.5 times the original acquisition rate. While the ADSP is hardware-based, it can accommodate a large variety of modes and missions. The engineering model will be adapted as the core processor for missions

such as Magellan, Shuttle Imaging Radar C, and other Earth-orbiting radar systems.

#### AUTOMATION AND ROBOTICS PROGRAM

Another way JPL advances technology and its uses is through the Automation and Robotics Program.

##### Telerobotics

JPL completed the preliminary design for a laboratory telerobot to be demonstrated in 1988. The diverse technologies of sensing and perception, task planning and reasoning, control execution, and operator interface were integrated into a design using one camera arm for the vision system and two manipulator arms. What is unique is the ability to change from an autonomous (robotic) control mode with operator supervision to a teleoperation control mode with the operator manipulating the hand controllers.

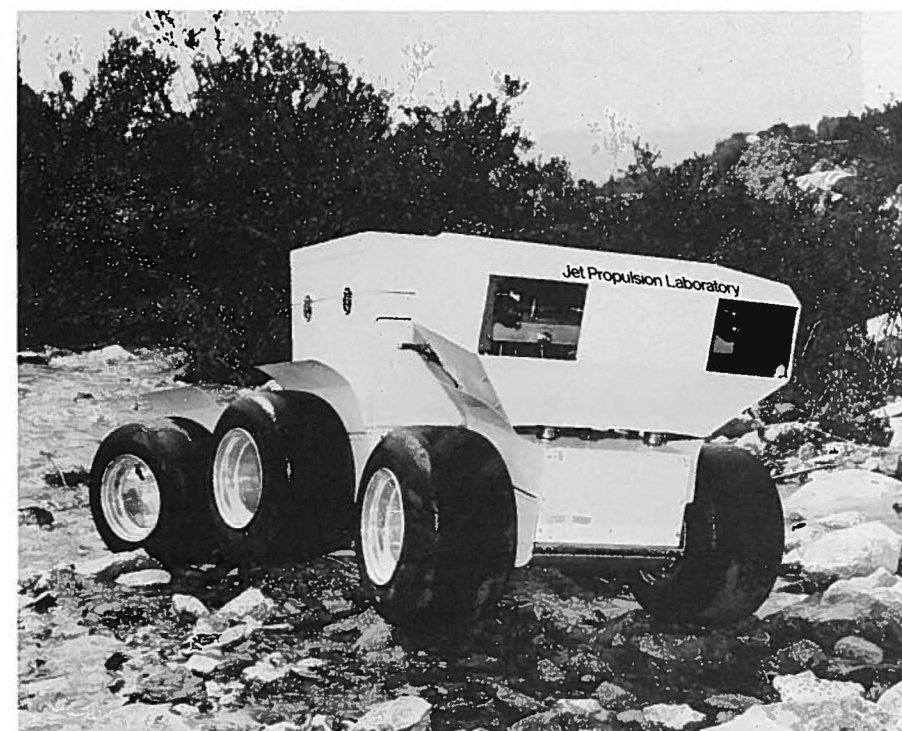
The technology of sensing and perception provides information to a telerobot about its

environment with the eventual goal of developing machine-vision hardware and software to acquire and track satellites for capture by the telerobot. This would allow the space shuttle to retrieve satellites for return to Earth or on-orbit repair. Activities this year focused on creating a computer network and test bed for the 1988 telerobot demonstration. A large fixture was developed to calibrate the vision and manipulator system to 1-millimeter precision in a 3- by 2- by 1-meter work volume with a 1-millisecond synchronization between the vision system and the manipulator arms.

##### Artificial Intelligence

Artificial intelligence technology is beginning to leave the laboratory and find cost-effective applications. One is in scheduling. The PLAN-IT expert system uses strategies that mimic the human expert planner to develop conflict-free schedules. The operator interacts with the system so that additional information can be obtained to change the planning criteria when conflicts arise that cannot be resolved by shuffling the order and timing of events. The expert system is gaining acceptance in many applications including Spacelab planning at Marshall Space Flight Center, space station power subsystem planning at Lewis Research Center, and Deep Space Network scheduling at JPL.

Projects such as the automated roving vehicle give scientists and engineers the opportunity to develop the technology for future missions to the surface of Mars. The combination of autonomy and artificial intelligence must play a major role in guiding a Mars rover across Martian terrain with little help from Earth.





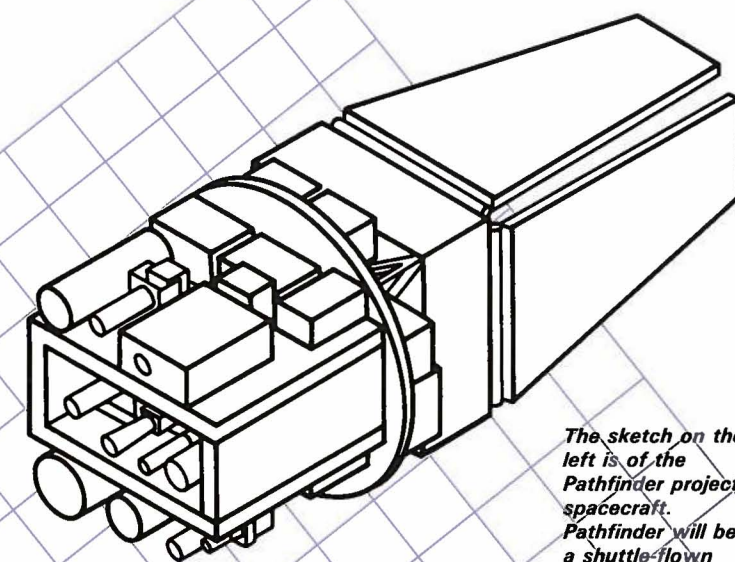
**C**omplementing JPL's research and advanced-technology development is the Defense and Civil Programs Office. The programs are examples of the growing synergy between JPL's research and development for non-NASA sponsors and its ongoing NASA work, programs that are providing nationally significant contributions to the science of information and intelligence-processing systems.

In addition to the tasks described here, JPL is working on unmanned aerial vehicle systems, the simulation of weapons' effects, emergency communication networks, and the mapping of atmospheric pollutants.

#### ASAS/ENSCE

The development of the All Source Analysis System/Enemy Situation Correlation Element (ASAS/ENSCE) project continued. Its mission is to field a baseline data-processing system for the U.S. Army and Air Force tactical intelligence needs in the early 1990s.

ASAS/ENSCE uses computer work stations in mobile field modules. They receive large quantities of intelligence data, analyze and prioritize them, and then process the data for battlefield commanders. JPL delivered two



*The sketch on the left is of the Pathfinder project spacecraft. Pathfinder will be a shuttle-flown experiment to demonstrate the technologies associated with the acquisition and tracking of missile-booster plumes.*

*A U.S. Army soldier (left) works at a portable analysis work station developed for the All Source Analysis System/Enemy Situation Correlation Element. The project's mission is to field a baseline data-processing system for the U.S. Army and Air Force.*

#### PATHFINDER

JPL initiated the Pathfinder project, a shuttle-based acquisition and tracking experiment, for the Strategic Defense Initiative Organization. The project's two major goals are to demonstrate technologies associated with (1) tracking a missile-booster plume and (2) acquiring data on the plume from which its signature and relationship to the booster can be derived.

Progress was made in designing the mission, conducting the preliminary design, and starting to build test and proto-flight hardware.

The Pathfinder project was to fly as part of a shuttle mission in late 1987, but late in 1986 the Pathfinder project was told to adapt the existing design to a free-flying satellite for launch on an expendable vehicle. The launch date is expected to slip to 1990.

types of field modules to Fort Hood, Texas, for the 2nd Armored Division.

The Laboratory also continued the following:

- ☆ The system-level design of the Intelligence Data Processor module and the Communications Processing and Interface module.
- ☆ The design and coding of the next major software release.
- ☆ The development of a computer work station for use by ASAS/ENSCE but having the potential for a variety of Army-wide applications.



## INTERACTIONS MEASUREMENT PAYLOAD FOR SHUTTLE

The definition studies for the Interactions Measurement Payload for Shuttle (IMPS) were completed for the U.S. Air Force Geophysics Laboratory. The goal is to obtain design criteria for spacecraft to be launched to highly inclined orbits where the polar/auroral environment has severe effects on space systems. IMPS will be launched in the 1990s and will provide science and engineering data on the hazards to astronauts and equipment in that environment. JPL will provide one experiment, called Photovoltaic Array Space Power, for the first IMPS flight.

## THE JOINT EXERCISE SUPPORT SYSTEM

The development of the initial operational version of the Joint Exercise Support System (JESS) was completed. A computer-based training system for corps and division commanders and staffs, JESS simulates many battlefield activities and conditions in a multiservice command-post exercise environment. JESS is the first computer system used to train military officers and personnel on a large scale. A JESS prototype at Fort Lewis, Washington, supported exercises involving 2,000 to 3,000 personnel.

## FLAT-PLATE SOLAR ARRAY

After a decade of progress, the Flat-Plate Solar Array project ended late in the year. The project began in January 1975 and channeled \$235 million into technology development to lower the manufacturing cost and improve the efficiency and reliability of flat-plate photovoltaic modules in terrestrial applications.

Largely through the project, prices for commercial products were reduced 15-fold since 1975, and current technology reduces costs by another factor

of three. The lifetime of a module has progressed from an unanswered question in 1975 to modules with lifetimes of 20 years and warranties of ten years. From the 6-percent efficiencies common in 1975, the commercial products have improved to 10-percent efficiencies, and prototypes exhibit efficiencies of more than 15 percent.

In summary, the Laboratory served as a catalyst in transforming the photovoltaics industry from a low-volume space/defense-oriented business to one that competes effectively in the commercial sector.

## ENERGY SYSTEMS TECHNOLOGY

In support of the electric vehicle program at the Electric Power Research Institute, JPL developed a high-performance, sealed, lead-acid battery. Engineering models at the cell level were constructed and tested. Calcium-tin-lead alloy cells accrued more than 500 cycles and demonstrated initial specific energy of 25 watt-hours per kilogram and specific power in excess of 150 watts per kilogram, both at 299.85 kelvins (26.7 degrees Celsius).

When testing ended, there was no indication of imminent cell failure, and specific power and cycle-life goals were exceeded. The specific energy goal is expected to be met with refined engineering models.

To measure the electric field near high-voltage AC and DC transmission lines, JPL developed miniaturized AC and DC electric-field meters. A prototype DC meter was tested at the National Bureau of Standards (NBS) and found to have an accuracy of the same order as its uncertainty in the NBS calibration equipment, about 1 to 2 percent, depending on the extent of the ion current induced by a space charge.

## INDUSTRIAL PROCESS INSTRUMENTATION RESEARCH

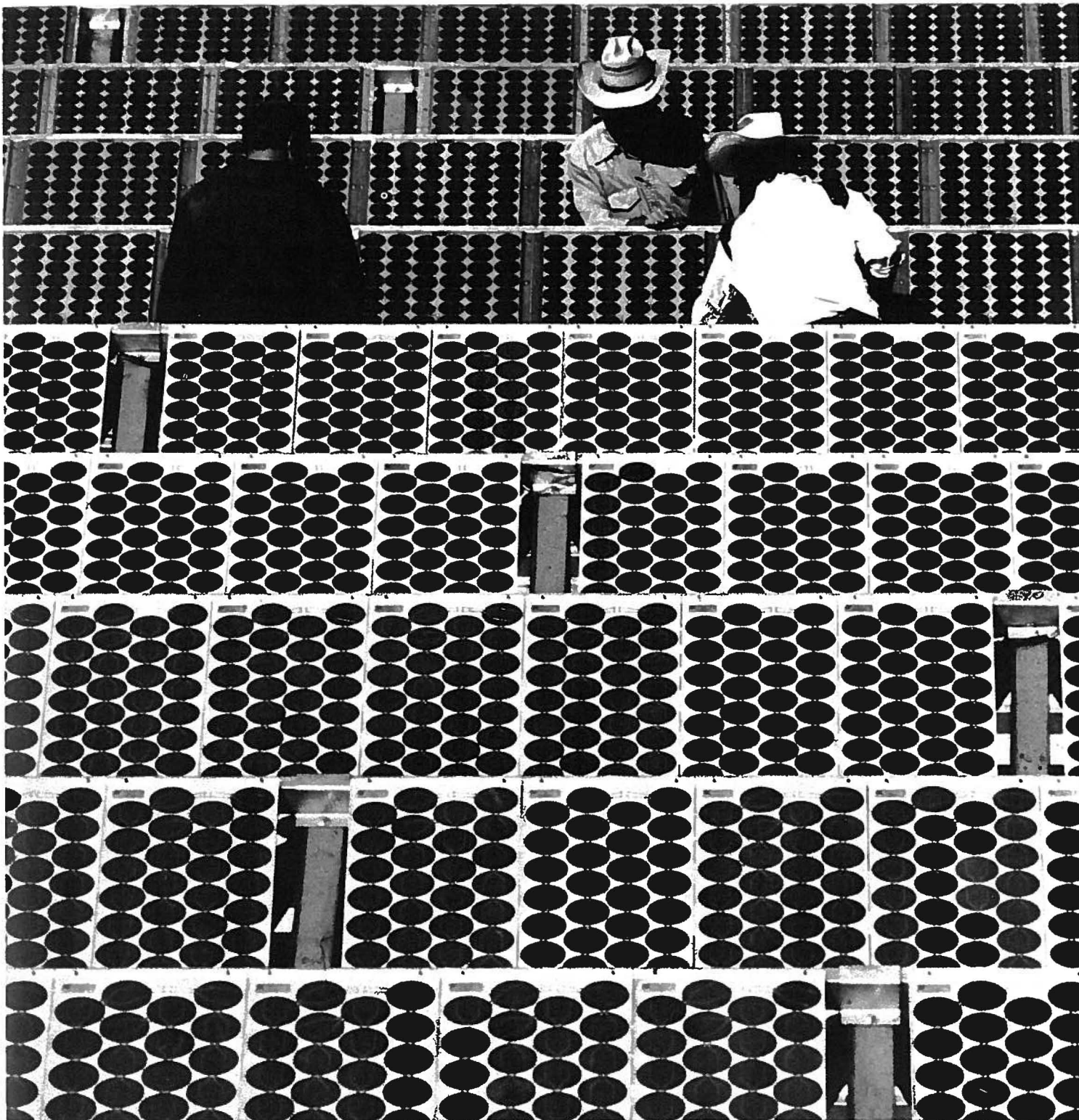
Several needed advanced sensors were identified for use in the paper and pulp industry. Four sensors being developed at JPL could improve productivity and conserve energy:

- ☆ A polymer hygrometer will meet the need for a rugged, reliable sensor that determines the relative humidity in dryer hoods. The hygrometer is based on the solid polymer electrolyte Nafion, whose resistance is a function of temperature and humidity.
- ☆ An on-line pyrolysis mass spectrometer will measure the lignin content in paper pulp. The detector is an ion trap that uses radio-frequency fields to achieve mass separation.
- ☆ An acoustic temperature profiler measures the time of flight of sound pulses in a known gas (usually air) in thermal equilibrium with the hot gases. Temperature-profile measurements are used in controlling the process in lime kilns.
- ☆ A steam-flow meter uses flow-generated sound in large steam pipes. The sensor measures the phase difference between two locations separated by a half-wavelength to obtain mean flow velocity. Also measured is the frequency of the steam whistle, which is a function of temperature.

## ZIRCONIA OXYGEN SEPARATOR

Solid-state ionics research led to the development of a cell that separates oxygen from air. The cell consists of an yttria-stabilized zirconia disk with a radial flow design that reduces power consumption in the separation cell. Separation cells that produce 30 cubic centimeters per minute of oxygen were tested. Oxygen purity levels near 100 percent are expected.

*Workers check an array of solar photovoltaic test modules developed by JPL's Flat-Plate Solar Array project. The Laboratory's work on the alternative source of energy, which ended after a decade of progress, was largely responsible for driving down the cost of commercial flat-plate photovoltaic modules.*



The applications of the process include the separation of oxygen (for medical purposes) and other gases from air. Of particular importance to NASA are the production of oxygen from the carbon dioxide atmosphere of Mars, the regeneration of oxygen in closed-habitat space environments, and the production of oxygen for propulsion.

## REMOTE SENSING OF METEOROLOGICAL PARAMETERS

The Microwave Atmospheric Remote Sensing (MARS) temperature profiler was operated at Denver's Stapleton International Airport from July 1985 to October 1986. The observations were intended to determine how well MARS can profile upper-air temperatures when deployed for routine, unattended operation. The standard for comparison was radiosonde temperature

*The MARS van awaits proper weather conditions to profile upper-air temperatures. Video displays of the profiles can be transmitted from the van to any standard terminal at two-minute intervals.*



profiles. The MARS performance was also compared with two other temperature-profiling systems, JPL's buoy system and the temperature profiler of the National Oceanographic and Atmospheric Administration.

Ten months of routine data have been analyzed, and the MARS temperature profiles have been produced. Performance statistics show that the root-mean-square (RMS) agreement with radiosondes is essentially the same as pre-experiment predictions for most altitudes. For altitudes below 2,000 feet above ground level, the MARS-derived air temperatures exhibit an RMS difference with radiosonde values that is approximately 1.0 degree Celsius: RMS agreement is 2 degrees Celsius at 10,000 feet, and 3 degrees Celsius at 20,000 feet.

The results suggest that MARS offers a low-cost alternative for obtaining routine temperature profiles to support weather prediction.

## BIOCATALYSIS

Work sponsored by the U.S. Department of Energy focuses on new bioprocess applications to resolve the technical constraints that impede the biocatalyzed production of chemicals and materials. Generic data and predictive theoretical models for biochemical catalysis are being produced. The task consists of three major elements, each addressing a key technical problem:

- ☆ In molecular modeling and applied genetics, computer-graphics models were advanced to predict the dynamic behavior and intramolecular rearrangement of biocatalysts. High-speed measuring methods using flow cytometry were developed to allow a

researcher to assay in three hours the fraction of information-bearing cells in a recombinant population. That is more than an order of magnitude faster than present methods. The results have been used to develop a new theory of plasmid stability that recognizes the limited capacity of plasmid-free cells to grow in a selective medium.

- ☆ Bioprocess engineering defines the engineering relationships between cellular scale events and the macrolevel parameters that enhance bioreactor productivity. An advanced fluidized-bed bioreactor with high cell-densities allows bioreactor productivities ten times those of conventional processes. The rates and extent of synthesis were improved in enzyme reactions that promote chemical transformations in organic solvents (as opposed to a conventional aqueous medium).
- ☆ In process design and analysis, user-friendly computer programs are being developed to assess the energetics and economics of biocatalyzed chemical production processes.

## COMMAND AND CONTROL AUTOMATION

The year brought significant achievements on two systems for the Air Force Military Airlift Command (MAC), which has a global airlift mission that is very active in peacetime as well as wartime.

The Global Decision Support System is a prototype command and control system that

serves interim operational needs for the top three MAC echelons. A distributed, replicated database exists on a worldwide network with applications programs available in five functional areas: command and control, transportation, logistics, operations, and graphics. Each site may read from or write to the common database for both command and airlift-resource information. The prototype system also serves as a model to demonstrate state-of-the-art equipment for upgrading other DOD command centers. The hardware and software were initially installed at MAC Headquarters, Scott Air Force Base, and four prime MAC bases.

The Distributed Management Information and Control System is a proof-of-concept system for the airlift wing echelon. The test bed was implemented at McChord Air Force Base, Washington, and is generating information to help the Air Force prepare specifications for its future information-processing systems.

## VOICE SWITCHING AND CONTROL SYSTEM

In 1986 the Voice Switching and Control System (VSCS) Project received approval from the Federal Aviation Administration (FAA) to develop a Traffic Simulation Unit (TSU). The initial planning and specifications are complete. The TSU is an independent testing device designed to provide the FAA with an objective means of evaluating the VSCS prototype.

Part of the FAA's National Airspace System upgrade, the VSCS is an automated voice-switching system that integrates radio and telephone/intercom services for air traffic controllers in new Area Control Facilities.

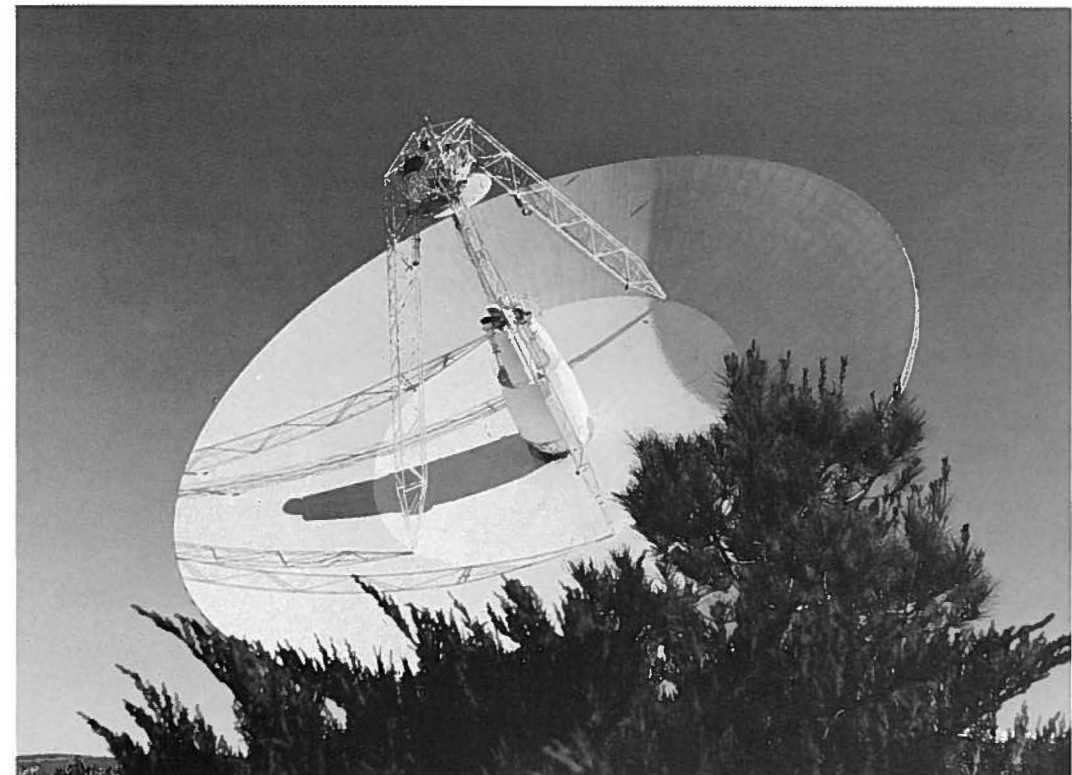
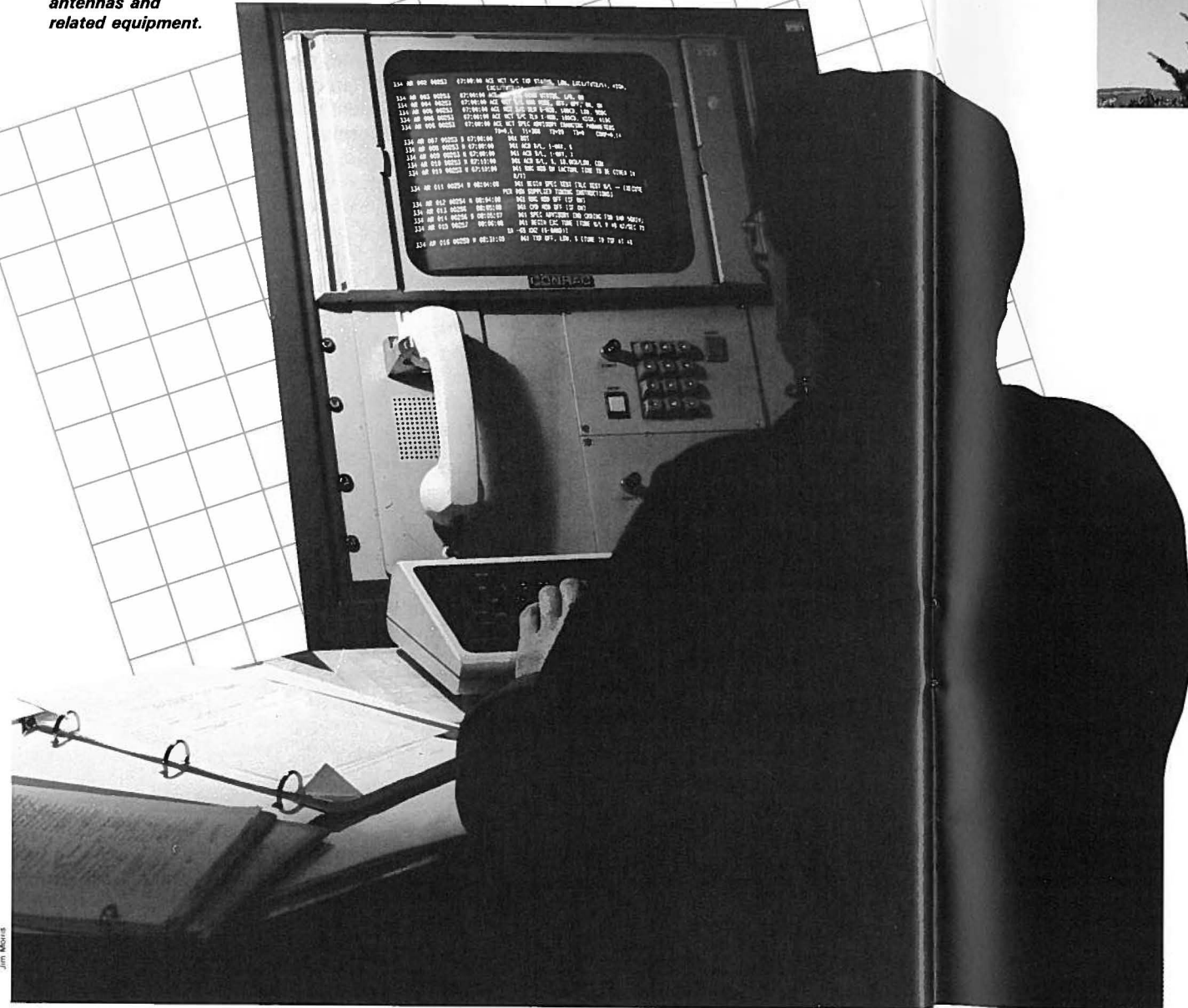


**E**stablished in 1958 to support Explorer 1, the Deep Space Network (DSN) is NASA's worldwide system for communicating with spacecraft exploring the solar system. Its antennas are clustered at Goldstone in the Mojave Desert; near Madrid, Spain; and near Canberra, Australia. The locations ensure that spacecraft are almost never out of view. The DSN has grown to include 11 antenna systems (a 12th is under construction), a Network Operations Control Center and facilities at JPL, and communications links to all locations.

Each complex has a 64-meter-diameter antenna. Those giants will soon be improved in efficiency and expanded in diameter to 70 meters. Smaller antennas at each complex—26 and 34 meters—were joined at Goldstone and Canberra by the new 34-meter, high-efficiency antennas in time for Voyager 2's Uranus encounter. A third new 34-meter antenna at Madrid will soon be in operation.

The complexes can be teamed for scientific investigations using techniques like very long baseline interferometry (VLBI), in which measurements by two or more antennas are combined to obtain the resolving power of an antenna that spans the distance between them. The VLBI technique is used to navigate spacecraft and make geodetic measurements.

*A technician in the Network Operations Control Center at JPL monitors data from one of the many U.S. and foreign spacecraft tracked by the Deep Space Network in 1986. The Network Operations Control Center is the heart of the Deep Space Network's global array of space antennas and related equipment.*

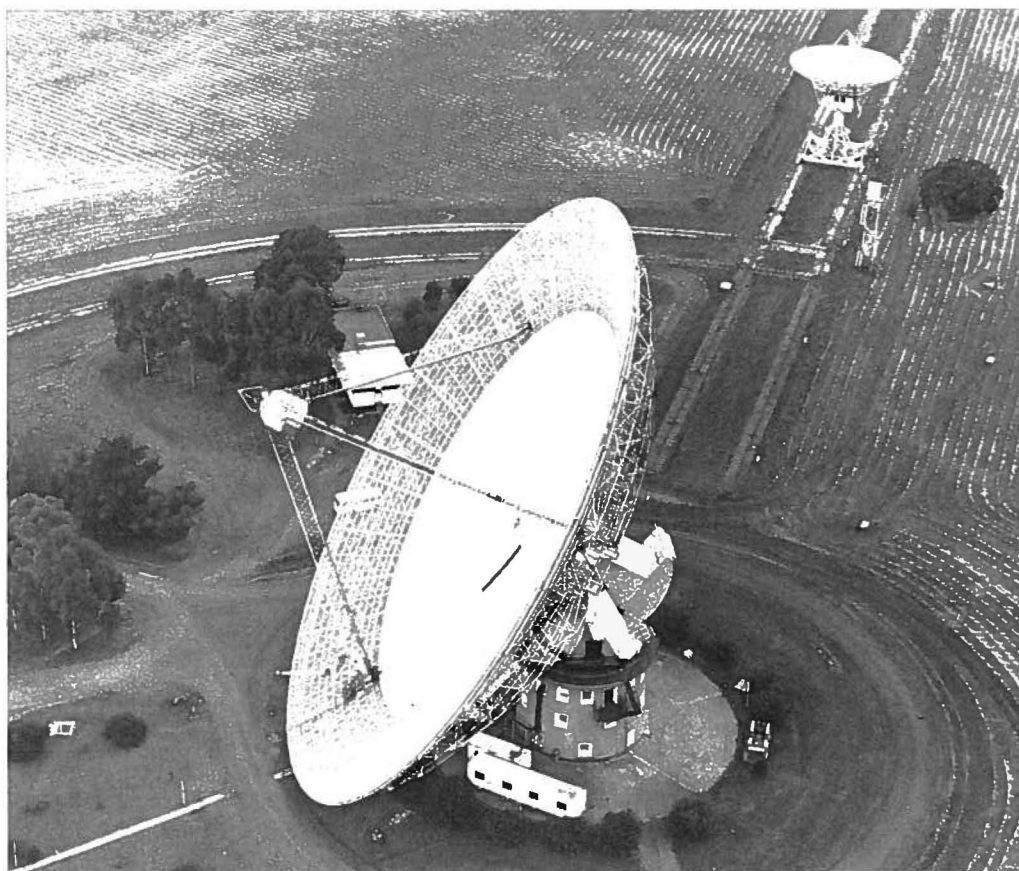


*The 64-meter antenna of the Deep Space Network at Goldstone, California, will be upgraded to 70 meters in diameter and its efficiency will be increased. Both improvements anticipate future missions to distant planets in the solar system.*

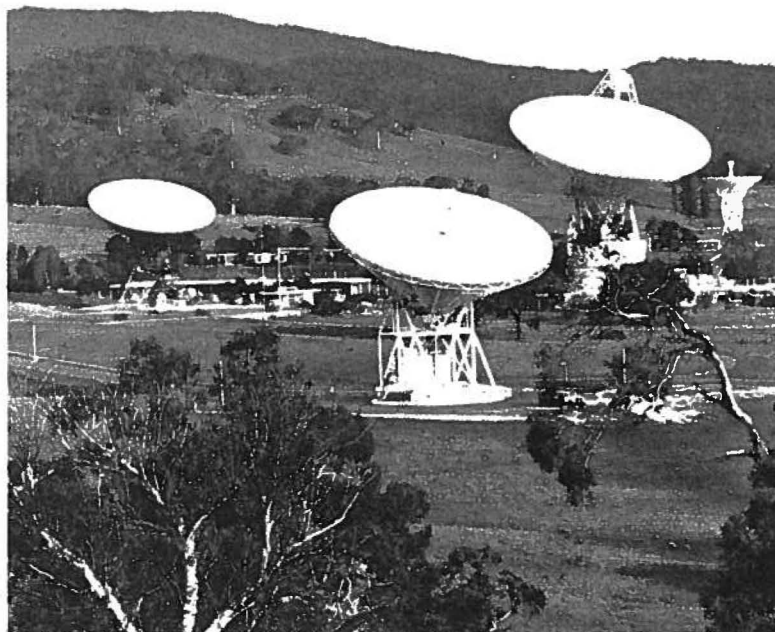
*Although the Challenger accident prevented the launch of many U.S. spacecraft, the Deep Space Network was busy tracking craft that were already flying, as noted in the table on the right.*

#### Projects supported by the DSN in 1986

| Mission  | Project Management                           |
|--|--|
| Voyagers 1 and 2                               | JPL  |
| Pioneer  | Ames Research Center                         |
| Giotto   | European Space Agency                        |
| Sakigake                                       | Institute of Space and Astronautical Science |
| Suisei   | Institute of Space and Astronautical Science |
| International Cometary Explorer                | Goddard Space Flight Center                  |
| Nimbus-7                                       | Goddard Space Flight Center                  |
| Dynamic Explorer-1                             | Goddard Space Flight Center                  |
| International Sun-Earth Explorers 1 and 2      | Goddard Space Flight Center                  |
| Vegas 1 and 2                                  | Soviet Union                                 |
| Active Magnetospheric Particle Tracer Explorer | Goddard Space Flight Center                  |



*The great radio telescope at the Parkes Radio Astronomy Observatory in Australia (above) was arrayed with the DSN antennas at Canberra, Australia (right), to track and acquire data from Voyager 2 during its encounter with Uranus.*



Communicating with spacecraft in deep space will always be its primary focus, but the DSN also supports Earth orbiters that are not compatible with NASA's Tracking and Data Relay Satellite System.

### **ARRAYING FOR VOYAGER**

The Voyager 2 encounter with Uranus represented the most significant challenge to deep-space data-capture. Voyager 2's X-band radio signal was about one-tenth as strong as at Jupiter in 1979. The improvements to the DSN complemented the improvements in Voyager 2's flight-data-system program. All DSN antennas at each complex were arrayed to effect the equivalent of a single antenna equal in area to the sum of the individual antennas.

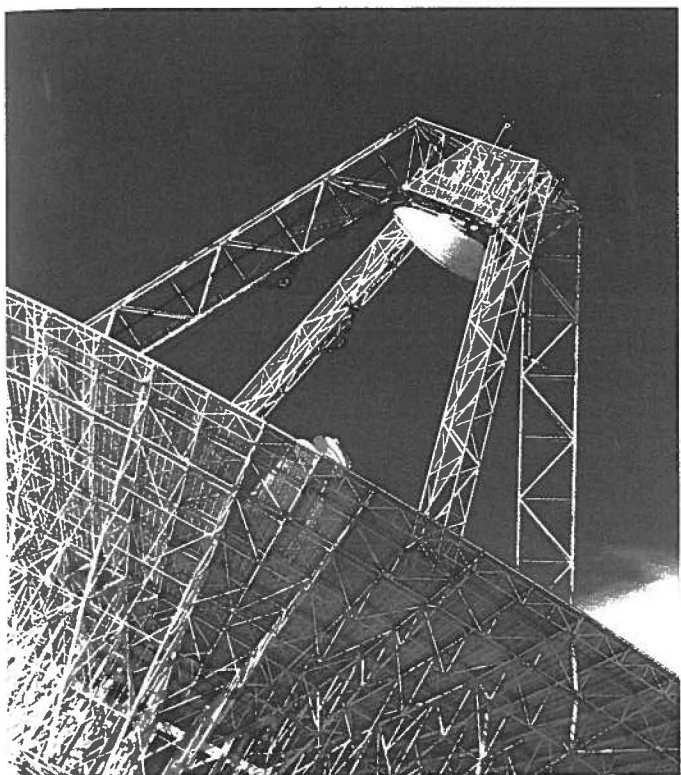
The arrays, including the new 34-meter antennas at Goldstone and Canberra, increased the potential data return by more than 50 percent compared to what the 64-meter antennas could have returned without arraying. The Parkes Radio Telescope in Australia joined the DSN to create an additional 50 percent increase there.

### **NEW ANTENNA DESIGN WITH A BEAM-WAVEGUIDE FEED SYSTEM**

The designs of a 34-meter experimental antenna with a beam-waveguide feed system have been explored in anticipation of future construction.

In a beam-waveguide feed system, the electromagnetic radiation is guided and focused by metallic reflectors to an electronics room that houses transmitters and low-noise amplifiers. The room can be decoupled from the tipping motion of the antenna and located near power and liquid supply lines on the ground.





*The photograph on the left shows a closeup of the 64-meter antenna at Goldstone, California, as it listens for data from a spacecraft near the edge of the solar system. The large antenna in the photograph below is the 26-meter Apollo station at the Goldstone DSN complex. A 9-meter antenna (lower right) supports Earth-orbiting satellites, and the antenna in the upper left is a ground station for satellite communications.*

Because the beam-waveguide feed design has significant advantages, it is expected that all future DSN antennas will be of the beam-waveguide feed type.

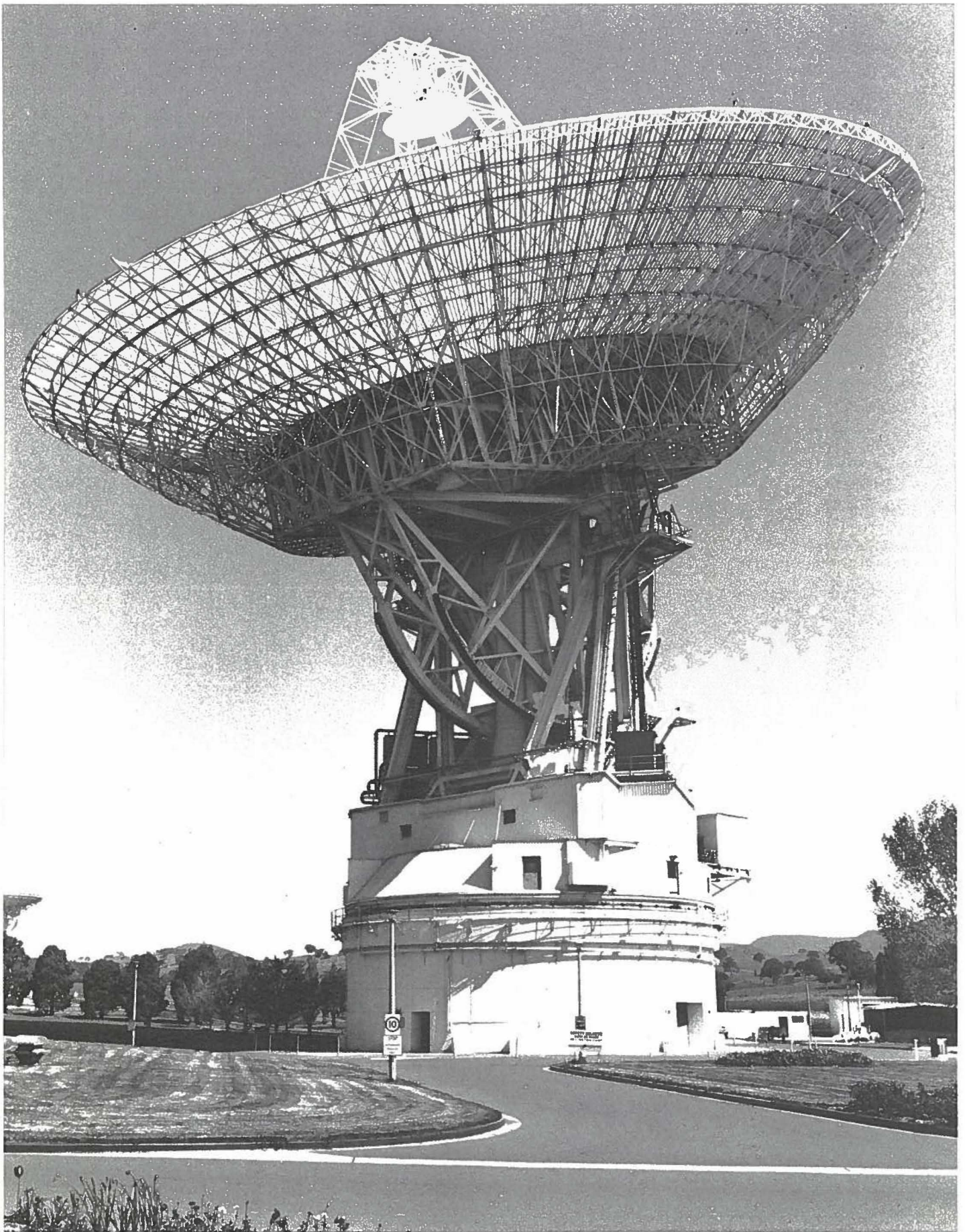
### **COMPUTER ANALYSIS OF WAVEGUIDE COMPONENTS**

The engineering design of microwave components in a circular waveguide has largely been a matter of trial and error, using mathematical models and experimental data.

But now three computer-aided-design tools have been completed that allow engineers to design waveguide devices whose performance agrees with computer-predicted results. Engineers are thus able to optimize their designs before cutting metal and can expect the first unit to meet specifications.









## VLBI OBSERVATIONS FROM SPACE

JPL scientists led an international team that accomplished the first VLBI experiment using an orbiting satellite as one of the receiving stations. The experiment demonstrated the feasibility of the proposed Quasar Satellite (QUASAT) project, in which a dedicated VLBI antenna would be placed in Earth orbit.

Using an antenna on NASA's Tracking and Data Relay Satellite as a radio telescope, the experiment transmitted wide-band data from the satellite to its ground station at White Sands, New Mexico, where the data were recorded. Later, the data were correlated with data received by Earth-based radio telescopes. The main ground telescopes were the DSN's 64-meter antenna in Australia and the 64-meter antenna of the Japanese Institute for Space and Astronautical Sciences at Usuda, Japan.

Three quasars were observed using a bandwidth centered at 2278 megahertz: 1730-130 (NRAO 530), 1741-038, and 1510-089. The maximum projected baselines of the space-to-ground interferometers exceeded the Earth's diameter (12,750 kilometers) for all three quasars. The longest projected baseline achieved during the experiment was 1.4 times the diameter of the Earth.

## HALLEY PATHFINDER

In 1981, the Interagency Consultative Group (with European, Soviet, Japanese, and American space agency representatives) conceived the idea of using the two Soviet Vega missions to Comet Halley as pathfinders for Giotto. The Vegas could assist Giotto because they would approach Halley first and because Giotto's data requirements were severe: Its goal was to pass by

Halley's nucleus, on the illuminated side, at a distance of about 500 kilometers.

Determining the comet's position was a two-stage process. First, radio metric data were used to construct an accurate trajectory for the Soviet Vegas; and second, the position of Halley's comet as it changed with respect to the Vegas was determined by using onboard imaging systems for optical navigation. Combining the two processes yielded the desired result.

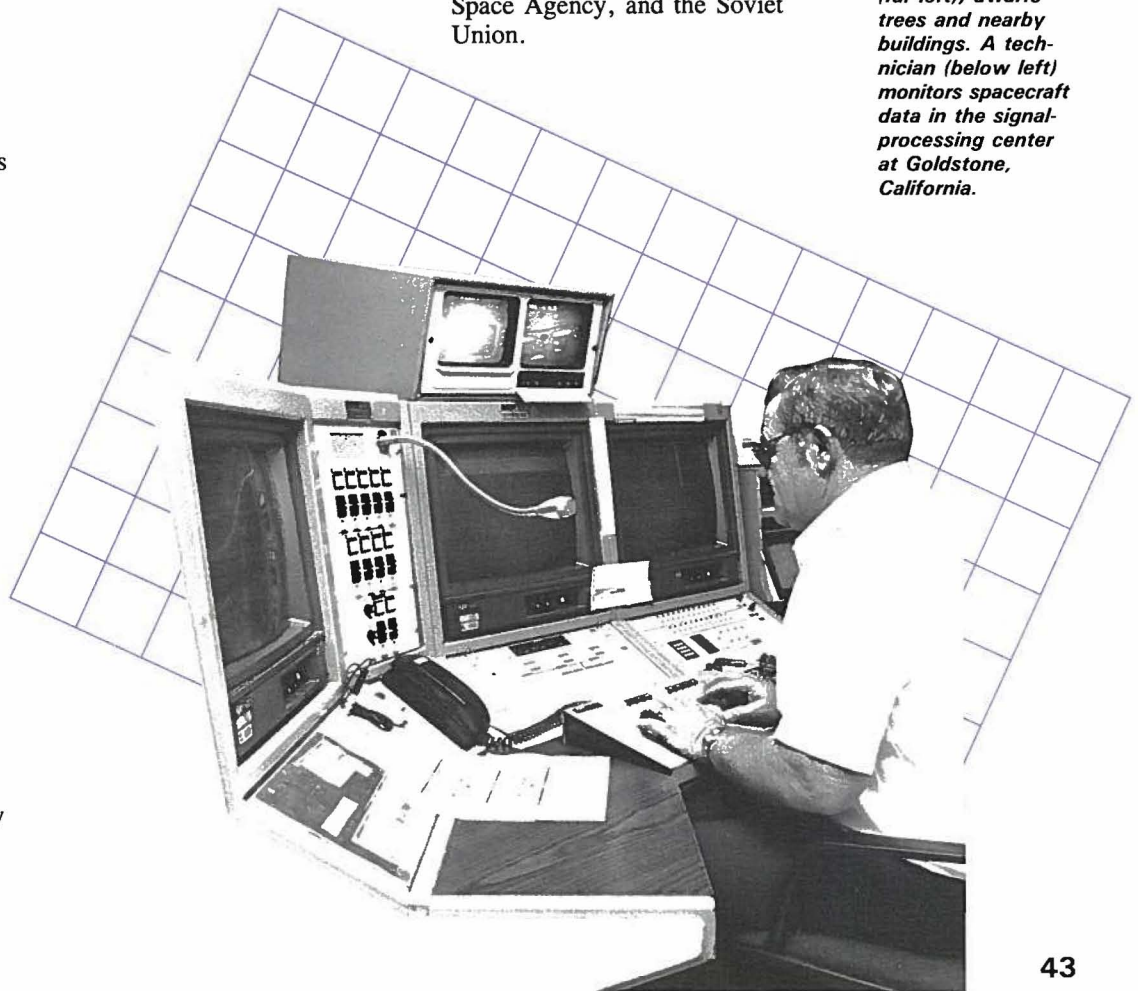
The single-station conventional radio metric data, acquired twice weekly by the Soviet tracking network, could provide an accuracy of 400 kilometers for Vega. To provide the information Giotto needed, though, required much higher accuracy in the Vega orbits. The higher accuracy was achieved with DSN observations. Seven observations were obtained in February 1986 and three in early March.

The final observation for Vega 1 took place on March 3, before Vega 1's encounter on March 6. The corresponding dates for Vega 2 were March 4 and 9.

The data were processed at JPL and forwarded to engineers at the Institute for Space Research, Moscow. JPL and the Russians then independently determined the Vega orbits using the same data. The Soviet onboard optical data and JPL's Vega orbit solutions were provided to the Giotto navigation team for final planning.

The final orbit determination for Vega was accurate to about 40 kilometers, enabling Giotto to be aimed 540 kilometers from the nucleus—500 kilometers plus the safety margin. Preliminary indications placed the actual flyby point of Giotto at 600 kilometers from the nucleus. The high-resolution images acquired by Giotto resulted from the coordination and international cooperation of the DSN, the European Space Agency, and the Soviet Union.

*The huge 64-meter antenna at the DSN complex near Canberra, Australia (far left), dwarfs trees and nearby buildings. A technician (below left) monitors spacecraft data in the signal-processing center at Goldstone, California.*





**R**esearch and development costs for the fiscal year ending in September were \$821 million, a 26-percent increase over fiscal 1985.

Costs for NASA-funded activities rose 12 percent to \$528 million. Defense and Civil Programs costs amounted to \$286 million, a 71-percent increase compared to the costs for those programs in 1985. The JPL work force increased to 5,393 from 5,247 in 1985 and 5,142 in 1984.

Procurement obligations during the fiscal year totaled \$580 million, 49 percent higher than in the previous year. The total included \$539 million to business firms, of which \$180 million went to small businesses and \$15.5 million to minority-owned businesses.

The Caltech-financed 170,000-square-foot Central Engineering Building was dedicated in July, only 14 months after construction began. Occupancy was completed in October when the last of more than 900 people moved in. More than 300 of them returned from off-Laboratory leased space, beginning the process of reducing leased space. Work continued on the 98,000-square-foot Earth and Space Science Laboratory, the second major step in the long-range plan to renew facilities. Successful bids were obtained in October for the new 39,000-square-foot Micro-devices Laboratory, designed to support research and development efforts in advanced microelectronics.



## INSTITUTIONAL LOCAL AREA NETWORK

A data communications network has been implemented throughout the Laboratory. The Institutional Local Area Network (ILAN) can connect data-communications devices in any JPL building in Pasadena. In addition, a communications bridge has been installed between the ILAN and the Caltech campus network.

The ILAN includes both low-speed (up to 19.2 kilobits per second) and high-speed (up to 5 megabits per second) subsystems that enable a wide variety of microcomputer-based work stations, minicomputers, and mainframe computers to communicate with each other and to access network-attached services, including the JPL Electronic Mail System, query databases, general-purpose computers, NASA Telemail, and other external networks and services.

## PATENTS AND TECHNOLOGY UTILIZATION

In helping NASA to provide the public with information, the Office of Patents and Technology Utilization reports, evaluates, and patents the inventions and technological innovations resulting from JPL work. JPL reported 220 inventions and innovations to NASA and other sponsors, and the U.S. Patent Office issued 29 patents to Caltech and NASA for JPL inventions.

The Office of Patents and Technology Utilization also filled requests from 31,449 individuals and companies for information on subjects included in NASA Tech Briefs.

NASA made the following exceptional monetary awards:

- ☆ To Marshall E. Alper, Robert M. Bamford, and 11 non-JPL awardees for "Original Specifications for the NASA General Purpose Digital Program for Structural Analysis," \$19,500, shared equally.

- ☆ To Dr. Alan Rembaum (now deceased) for "Origination of Important New Classes of Polymers and Significant Advancements in Polymer Chemistry," \$10,000.

- ☆ To James R. Janesick and Stythe T. Elliott for "CCD Imaging System," \$10,000 shared equally.

Another 183 JPL employees received minimum (\$250-\$500) and nominal (\$501-\$999) patent awards and Tech Brief (\$150) awards totaling \$32,250.

## NASA HONOR AWARDS

The NASA Honor Awards program recognizes outstanding individual and team efforts. In addition to the usual annual awards, many were made for contributions to the Voyager Uranus mission. Though presented on separate occasions, the awards are merged in the lists below. Many Exceptional Scientific Achievement Medals and Public Service Medals associated with the efforts were also awarded to non-JPL employees.

### NASA Distinguished Service Medal

Richard P. Laeser

### NASA Outstanding Leadership Medal

Douglas G. Griffith, Norman R. Haynes, Charles E. Kohlhasse, William I. McLaughlin, Raymond B. Morris, Allan L. Sacks, Edward C. Stone, George P. Textor, Paul T. Westmoreland

### NASA Exceptional Scientific Achievement Medal

Crofton B. Farmer  
Frank J. Grunthaner  
Arthur L. Lane  
Ellis D. Miner  
Taylor G. Wang

### NASA Exceptional Engineering Achievement Medal

Martin G. Buehler  
Edward H. Kopf, Jr.  
Howard P. Marderness  
Robertson Stevens

### NASA Equal Opportunity Medal

James King, Jr.



## NASA Exceptional Service Medal

James D. Acord, Terrence P. Adamski,  
James L. Anderson, Charles C. Avis,  
Charles A. Beswick,  
Edgar M. Blizzard,  
Robert N. Brooks, Jr.,  
Robert J. Cesarone, J. Pieter deVries,  
Peter E. Doms, Frank F. Donovan,  
Daniel F. Finnerty,  
James W. Gerschultz, Donald L. Gray,  
Gene A. Hanover, Eleanor F. Helin,  
Ronald M. Hungerford,  
Richard S. Lemon, Verl B. Lobb,  
Boyd D. Madsen, George M. Masters,  
Richard Moulder, Ray L. Newburn,  
Joseph H. Newman,  
Robert H. Norton, Jr.,  
Fred G. O'Callaghan, Michael A. Orr,  
Robert A. Preston,  
Charles M. Reynolds, Jr.,  
Richard J. Rice, Richard P. Rudd,  
Larry L. Simmons,  
Charles H. Stenbridge,  
Donald N. Sweetnam,  
Stephen P. Synnott,  
Stephen Z. Szirmay,  
Anthony H. Taylor, Harold L. Theiss,  
Neil N. Toy, Ben Toyoshima,  
Marvin R. Traxler, Michael G. Urban,  
Robert J. Wallace, Irving J. Webb,  
Donna M. Wolff, Donald K. Yeomans,  
Lawrence J. Zottarelli

## NASA Group Achievement Award

Atmospheric Trace Molecule  
Spectroscopy (ATMOS)  
Experiment Team

ATMOS Spacelab-3 Science Group  
All Source Analysis System (ASAS)  
Interface Module Brassboard  
Development Team

Development and Operations Team for  
Support of Missions to Halley's Comet

Development and Operations Team  
for Support of the Venus Balloon  
Experiment

Microgravity Science and Engineering  
Team

DSN Energy Conservation Project  
Team

Multimission Data Capture and  
Telemetry Processing Implementation  
Team

Mark IVA DSN Implementation Project  
Voyager Flight Team

Voyager Science Investigations

Voyager Uranus Encounter Support

Voyager Technical Assistance

Extraordinary Voyager Uranus Mission  
Engineering

OSSA Solar System Exploration  
Division—Voyager Uranus

Public Affairs Office—OSSA

Voyager Uranus OSTDS Ground  
Systems Division—DSN

Parkes-CDSCC Telemetry Array

## DIRECTOR'S DISCRETIONARY FUND

NASA increased the level of funding for the Director's Discretionary Fund (DDF) to \$3 million per year from \$2 million in 1985 and the \$1 million per year that had been in effect since 1980. The basic objectives of the Fund remain focused on providing initial support to innovative and seed efforts for which conventional funding is not available. The higher level of resources that now prevails enables expanded efforts in areas regarded as critical for the future of the Laboratory. Technological areas selected by the Director for special emphasis included advanced microelectronics, autonomous systems and robotics, infrared- and submillimeter-wavelength sensors, and extra-solar-system detection.

Selected from about 100 proposals, some 40 major tasks plus ten or so ad hoc support efforts were initiated with DDF support. Sixteen involve the collaboration with faculty and students at Caltech or other universities.

## PRESIDENT'S FUND

The Caltech President's Fund provides a second, though smaller, source of discretionary funding, currently \$1 million a year, half from NASA and half from Caltech. The Fund is administered by Caltech. In addition to financing scientific investigations, the Fund is intended to encourage and facilitate the collaboration of university faculty and students with JPL staff in research activities of importance to JPL. Seventeen tasks were begun that involve, besides Caltech, the University of Southern California, Arizona State University, Purdue University, San Diego State University, and the University of California at Riverside.



Laboratory employees received many honors at ceremonies through the year. This collage was made from photographs taken at the NASA Honor Awards Ceremony.

## PROGRAMS AND PLANNING

JPL teams studied deep-space missions to the moon, Mars, comets, asteroids, and the outer solar system.

The Laboratory is beginning the serious examination of sending probes to interstellar space. One such mission would send a nuclear powered spacecraft on a voyage lasting decades and traversing 1,000 times the distance of the Earth from the Sun.

The Laboratory continued to explore the use of Earth-orbiting telescopes to observe deep-space phenomena, including the birth of stars and planetary systems. Such studies help us to push back the frontiers of our knowledge and to prepare, perhaps, for human presence in deep space.

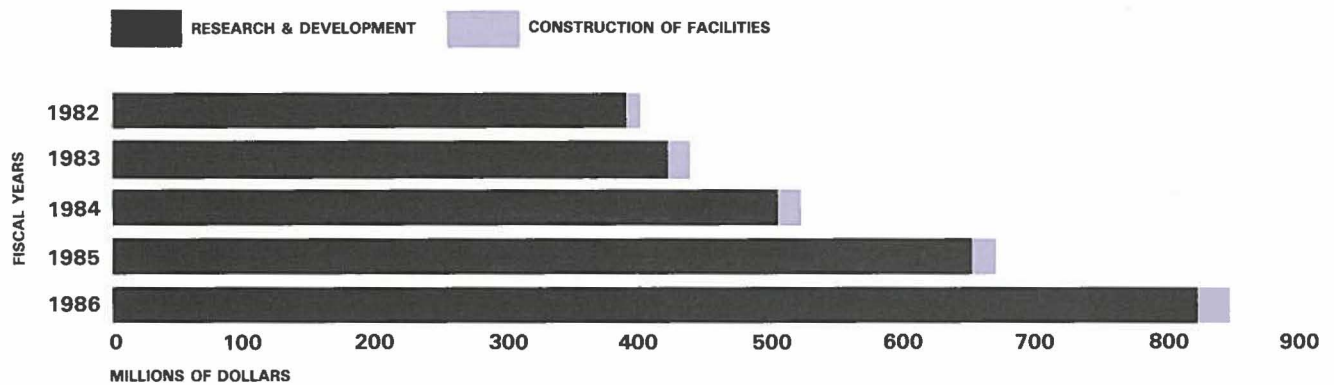
## DISTINGUISHED VISITING SCIENTIST PROGRAM

The purpose of the Distinguished Visiting Scientist Program is to bring to the Laboratory leading scientists who will enrich our programs. Program participants are listed on the right.

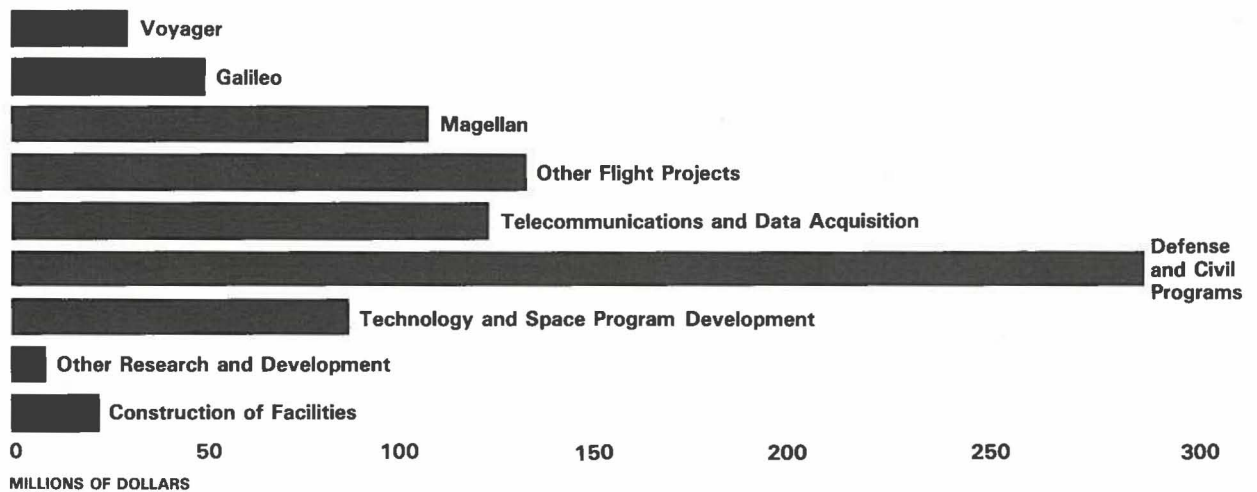
| Name                    | Affiliation                               | Field of Endeavor                     |
|-------------------------|---|---------------------------------------|
| Jacques Blamont         | Centre National d'Etudes Spatiales, Paris | Flight experiments                    |
| H. Fechtig              | Max-Planck Institut                       | Interplanetary dust, comets           |
| Richard Goody           | Harvard University                        | Earth and planetary sciences          |
| Klaus Hasselmann        | Max-Planck Institut                       | Ocean surface remote sensing          |
| Raymond Hide            | Meteorology Office, United Kingdom        | Geophysics, fluid dynamics            |
| Lewis Kaplan            | University of Chicago                     | Atmospheric spectroscopy              |
| Michael Longuet-Higgins | Cambridge                                 | Oceanic wave phenomena                |
| Pearn Niiler            | Scripps Institution of Oceanography       | Ocean circulation, surface heat flux  |
| S.I. Rasool             | Laboratoire de Meteorologie, Paris        | Land surface climatology              |
| Eugene Shoemaker        | U.S. Geological Survey                    | Asteroids                             |
| David Atlas             | University of Chicago                     | Radar meteorology                     |
| Guido Munch             | Max-Planck Institut                       | Astronomy                             |
| Nabil Farhat            | University of Pennsylvania                | Electro-optics                        |
| Donald Hunten           | University of Arizona                     | Planetary atmospheres                 |
| Michael Belton          | Kitt Peak National Observatory            | Planetary astronomy                   |
| Paul Tapponnier         | Institut de Physique du Globe de Paris    | Geodynamics                           |
| Philipp Hartl           | University of Stuttgart                   | Radar remote sensing                  |
| Eugene Levy             | University of Arizona                     | Extra-solar-system planetary research |
| Albert Overhouser       | Purdue University                         | Solid-state physics                   |
| Emanuel Peled           | Tel Aviv University                       | Electrochemistry                      |
| Carl Sagan              | Cornell University                        | Astronomy and space sciences          |
| Melvin Stern            | University of Rhode Island                | Geophysical fluid mechanics           |



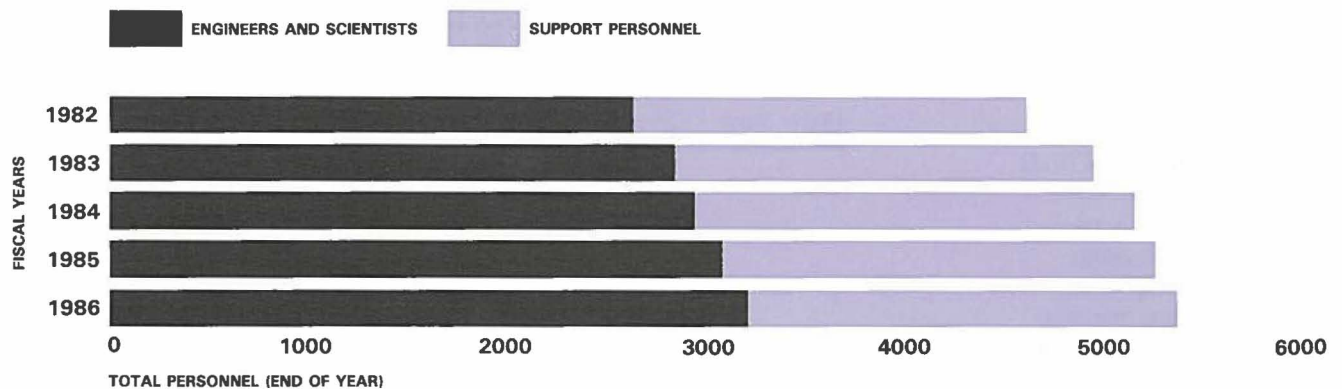
## TOTAL COSTS



## FISCAL 1986 COSTS



## PERSONNEL





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**ROBERT J. PARKS**  
*Deputy Director*

**MOUSTAFA T. CHAHINE**  
*Chief Scientist*

**FRANK COLELLA**  
*Manager—Public Affairs Office*

**DUANE F. DIPPREY**  
*Assistant Laboratory Director—  
Defense and Civil Programs*

**FRED H. FELBERG**  
*Associate Director—Institutional*

**DONALD R. FOWLER**  
*General Counsel*

**CLARENCE R. GATES**  
*Assistant Laboratory Director—  
Technical Divisions*

**W. GENE GIBERSON**  
*Assistant Laboratory Director—  
Flight Projects*

**JOHN HEIE**  
*Assistant Laboratory Director—  
Administrative Divisions*

**PETER T. LYMAN**  
*Assistant Laboratory Director—  
Telecommunications and Data  
Acquisition*

**DONALD G. REA**  
*Assistant Laboratory Director—  
Technology and Space Program  
Development*

**GEOFFREY ROBILLARD**  
*Assistant Laboratory Director—  
Engineering and Review*

**WALTER K. VICTOR**  
*Assistant Laboratory Director—  
Computing and Information Systems*

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